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HISTORY

61

OF THE

PROGRESS

AND

PRESENT STATE

OF

ANIMAL CHEMISTRY.

BY

W. B. JOHNSON, M. B.

IN THREE VOLUMES.

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VOL. III.

ERRATA.

Page 12, l. 14, *for every r. very*—P. 24, l. 2, *for gastric r. galvanic*—Page 155 is marked by mistake 115—Page 197, line 10 from bot. *for indigestion r. ingestion*—P. 207, l. 29, *for acid r. aid*—Page 229, l. 17, *for on the contrary, r. if, on the contrary*—P. 235, l. 10, *for matter of r. matter, of*—ib. l. 28, *for weight r. in weight*—P. 236, l. 13, *dele and*—P. 239, l. 16, *for A certain r. 't. A certain*—P. 267, l. 27, *for thus r. this*—P. 275, line 2 from bot. *for Daniel r. David*—P. 279, l. 15, *last century add but one.*

THE
HISTORY
OF
ANIMAL CHEMISTRY.

LIFE.

The Vital Principle.

THAT life is a material principle, and consequently subject to the laws of chemical affinities, has been asserted by several philosophers; but although no satisfactory explanation has yet been given respecting its action, or mode of producing its various effects, when considered in a chemical view, it will not be deviating from the object of the present work to give a few of the principal opinions that have been held of its nature.

The existence of a living principle in the animal body has been acknowledged from the earliest ages. At first it was looked upon as being particularly connected with the blood; for, having observed that the body was deprived of life by great evacuations of blood, either in battle or by accidental causes, it was natural to conclude that this fluid conveyed the living principle out of the wound, and pro-

Moses. duced death. This was the idea of Moses, and the reason why that legislator prohibited the Israelites from eating blood. "Therefore I said unto the children of Israel, Ye shall eat the blood of no manner of flesh; for the life of all flesh is the blood thereof. I will even set my face against that soul that eateth blood; for the life of the flesh is in the blood." Homer gives death the epithet purple, *πορφύρεος θάνατος*: and Virgil alludes to it when he says, *purpuream vomit ille animam*. Empedocles and Critias believed life to be the blood itself.

Upon examining the opinions of the ancient sects of philosophers, on the immateriality and materiality of the soul, it would appear, that the immaterialists, considering all the subtle and invisible fluids as not subject to the laws of matter, thought they had discovered amongst them the origin of the soul, whilst some of them seem to have con-

Heraclitus. founded the soul with the living principle. Thus Heraclitus looked upon the soul, or intelligent principle, as incorporeal, or an exhalation; Parmenides, that it was fire; Epithormus, that it was extracted from the sun; and Anaxagoras, Anaximenes, and Archelaus, that it was a subtle air. Hippo asserted it to be a vapour; for, according to him, humidity was the principle of all things; and Boëcius, that it was composed of air and fire. Marcus Antoninus the Stoic was persuaded of it's great resemblance to the wind, and Critolaus imagined that its essence was a fifth substance. Many of the moderns have supposed the soul originates from the seminal liquor; that at first it is merely a vegetating principle, like unto that of a plant, but afterward, on becoming more perfect, it acquires a sensitive property, and is at last rendered reasonable by the divine cooperation.

Pythagoras. Pythagoras had imagined the soul to be detached from the air, and had invented an *anima mundi*, from

which the souls of men were emanations : but as the reciprocal action of the soul and the body upon each other was not easily explained on the supposition of immateriality, Plato seems to have improved on the idea Plato. of Pythagoras, by proposing that of a *plastic nature*, a kind of intermediary living principle connecting the soul and body ; and this plastic principle was acknowledged even by Hippocrates and Aristotle, although differently modified by various sects. Aristotle the peripatetic, and Aristotle. the scholar of Plato, asserts the soul to be the first entelechia of the natural organic body, having the living principle under it's direction. It has three faculties ; the nutritive, the sensitive, and the rational. The first is that in which life is the only acting principle. The second is that by which feeling is produced. The third is peculiar to man, and is that part of him which knows and judges. This intellect is either an intellectum agens vel patiens. The first may be separated from the body, and is immortal : the other is perishable. Life is a permanence of the soul, according to this philosopher, retained by the natural heat, and the principle of this heat is in the heart. Galen. Galen was much attached to the doctrine of Aristotle, and made commentaries full of erudition on the works of that philosopher. Among the Arabs, Avicenna and Averroes were the principal who commented on the doctrine of the Stagyrte. Among the physicians of Italy that followed the same doctrine was Andrew Cefalpinus, first physician to Clement VIII ; and it ended with Corringius.

Leucippus, Democritus, and Epicurus were real materialists. Epicurus. They were of opinion there was nothing in existence but body, and that the principle of life and intelligence are only modifications of matter ; that they arise from the disposition of the atoms in organized bodies, in the same manner as the flesh, the blood, and other sensible parts.

Lactantius, who believed the soul likewise corporeal, after having examined all the various opinions of philosophers on the subject of the essence of which the soul is composed, and having regarded them all as uncertain, acknowledges, however, they are not without some share of truth—our soul, or the principle of life, being in the blood, in the heart, and in the spirit—but that it is impossible to express the nature which is the result, being more easy to see the operations of it than to define it.

It would appear, therefore, all the ancients had some idea of a living principle which animates the corporeal machine; and this is asserted by Plutarch, who ought to know best the sentiments of the ancients, having given a treatise on their opinions. He says, as being acknowledged by all of them, that spirit is only a subtile matter, and our soul, which is the air, keeps us alive; and in this manner all the world contains spirit and air, which are only two names signifying the same thing.

The *anima mundi* of Pythagoras, the *φύσις* of Hippocrates, and the *πνεύμα* of the author of *De Mundo*, was afterwards described by the name of *calidum innatum*, as expressing the vital principle: and some of the first restorers of letters adopted the same opinion: and during a considerable part of the seventeenth century, a regular system prevailed, by which the vital principle was reckoned the efficient cause of generation and existence in all animals and plants. It then took the name of *anima vegetans*.

Paracelsus. Paracelsus changed this term, in his hypothetical and fanciful method of reasoning, for that of *sidereal spirit*, which, according to his opinion, was equally independent of the body and the mind, but descended from the firmament, as the rational soul proceeded from the deity. Van Helmont, who thought he improved upon the system of his master Paracelsus, suggested the theory of the *Archeüs*, without venturing to assert the unity of the rational and

living souls. The actions of the Archeüs were afterwards reduced by Stahl to the operations of the *rational* Stahl. *soul*; but, according to Dr. Ferriar, Descartes appears to have been the first modern philosopher who rejected the separate existence of the vital principle, under all denominations. He availed himself of the progress that was made in the nervous physiology not long before, by Willis and others, to form an hypothesis of the vital functions, founded on the supposition of the nervous fluid or animal spirits, which was the language of that period. The doctrine of Stahl made considerable progress; and the supposition of a rational power, or *vis medicatrix naturæ*, which directs all the actions of the body both in health and disease, became universal; and for a long time the terms of nature, sensitive soul, and vital principle, were employed without much opposition. The existence of a nervous fluid was now assumed independently of the sensitive soul, to explain the appearances of sensation and voluntary motion.

About the middle of the last century, when Haller was asserting his theory of the *vis insita*, and *vis nervea*, Dr. Whytt of Edinburgh attempted a reformation of the Whytt. Stahlian doctrine, which excluded the independent living principle. He supposes the soul to be present in different parts of the brain at the same time, while he considers this soul as immaterial and unextended.

Some philosophers at length began to imagine that matter might acquire vitality, in consequence of a certain organization, and amongst these were Buffon and Hoff- Buffon. mann. But while no single hypothesis respecting the vital principle prevailed generally, two theories appeared, which more particularly engaged the attention. Dr. Monro gives Monro. his explanation of the *intellectus agens* in the body, by saying, that the power which created all things, which gave life to animals, continues to act upon and to maintain all,

Hunter.

by the unceasing influence of a living principle pervading the universe, the nature of which our faculties are incapable of duly comprehending. The other theory was that of John Hunter, who revived the idea of the blood being endued with the living principle. This opinion, as observed before, is not only to be found in the writings attributed to Moses, but in modern times it had been asserted by Harvey, Hoffmann, and more particularly by Huxham, who even mentions the red globules as the peculiar seat of life. The proofs which John Hunter brings of the life of the blood are the following : 1. It unites living parts when effused between them. 2. The blood becomes vascular, like other living parts. 3. It's temperature, as it flows from the vein, is always equal, in the most opposite temperatures to which the body can bear exposure. 4. It is capable of being acted upon by a stimulus, as is the case when it coagulates. 5. The last direct proof of the life of the blood is the nourishment and preservation of life in paralytic limbs.

Goodwyn.

Goodwyn, who endeavoured to consider the subject of vitality in a manner different from what it had been, taking the living body when all the accidental signs of life are removed, and applying to it those external powers which really do restore them, then attending to the place and circumstances of their first operation, and the immediate effects they produce, was led to examine the essential quality of life, and consequently to the means of distinguishing it from death. This physician is of opinion, that the heart is the great seat of the principle of life, in all the more perfect animals ; and that the contraction of the heart with the ordinary stimulus is the only mark of the presence of this principle ; that when the heart contracts, under such circumstances, the body is alive ; when not, it is dead. Life he therefore defines to be the faculty of propelling the fluids through the circulatory system. Ac-

According to him, the external concomitant circumstances which operate upon the body in health are heat and respiration, which excite the vital principle to action; and whenever the functions of an animal are suddenly suspended, and the body puts on the appearance of death, it is always in our power to determine whether it be really dead, by restoring the temperature, and by inflating the lungs with proper air. He is of opinion, with some others, that there are no means of determining the absolute deprivation of the vital principle but by the presence of putrefaction.

Currie, on appreciating the powers of life, affirms, that *Currie* if a definition of it were required, it might be most clearly established on that capacity by which the animal preserves its proper heat under the various degrees of temperature of the medium in which it exists. That the more perfect animals possess this power in a superior degree: and this is necessary from the exercise of their vital functions. That the inferior animals have it in a lower degree, and vegetables lower still; which is according to their limited powers and humbler organization. And as the capacity of preserving nearly an uniform temperature in all varieties of climate and season is a criterion of life in the more powerful animals, it is probable that a few degrees of increase or diminution of the heat of the system produce diseases and death. Metzler supposes carbonic acid gas to afford the principle of life. De la Metherie looks upon the principle *De la Metherie* of life to be the *aura animalis*, somewhat analogous to the *aura feminalis*; and Girtanner affirms irritability to be the principle of life. Somewhat before the time when Goodwyn published his "Connection of Life with Respiration," a revolution had taken place in chemistry, and the attention of philosophers became more particularly directed to investigate the chemical processes that were supposed to take place in the animal economy, and by which the principle of life came in for its share. This change

in the systems arose from the discovery of oxygen, which was found to be that principle which some of the ancients had imagined to exist in the atmosphere—a certain something which they saw was necessary to life. This oxygen is the pneuma that Aristotle says unites with the blood; and Chrysippus von Soli, who gave to the pneuma the most extensive range, expressly declares that it is what generates life; whilst Praxagoras the physician says that the soul is strengthened by spirituous air.

This theory of Chrysippus and Praxagoras had it's disciples in the middle ages, and in latter times it received great influence from the discovery of the circulation of the blood. For this discovery we are indebted to Michael Servetus or Andrew Celsapinus, each having mentioned that circumstance before Harvey. It now became clear where the blood met with the inspired air, and how it was then sent through the body. Servetus expressly says that the blood passes through the lungs, obtains there an addition of vital spirit from the atmospheric air, and returns impregnated with this from the lungs to the heart. Bacon added to the doctrine of the pneuma, and says the vital spirit is composed of air and fire, which by their union produce a weak combustion, or, as it may be called, the *phlegmatic* process of life (*incensio spirituum vitalium*). Hence, from the time of Praxagoras there appears to have been a similar idea of a *material principle* of life, although differently modified; and this appears to have been the opinion likewise of Harvey, Mayow, and Mund, and to have descended to the present times. Thus Townsend affirms, the vital force of an organ appears to be in the exact proportion of the quantity of oxygenated blood that circulates through it; Thornton, that there is a chemical process going forward in the body by means of oxygen; and Brandis, Reil, and Gallini are of the same opinion, but say the vital power arises from a constant change of animal

Bacon.

Townsend.

Thornton.

Brandis.

matter, a phlogistic process, which is maintained and renewed by an union of the oxygen with the carbon. According to Hufeland, life is a chemico-animal flame, to the production of which oxygen is absolutely necessary, and the vital power is the most general and powerful of all the powers of nature. He considers it as the cause of organization, and as possessing the following properties.

1. It has a greater affinity to some organized bodies than to others; thus, the polypus may be cut in pieces without being divested of it, and a decapitated tortoise or a frog deprived of its heart will live a long time after; whilst to the human body, or a quadruped, it would be instant death. According to this physiologist, it appears to be a general rule, that the stronger the affinity is between life and an organized being, the more imperfect is the animal: hence the zoophytes, whose whole organization consists in a mouth, a stomach, and a gut, have a life exceedingly tenacious, and difficult to be destroyed.
2. It is in greater quantity in some organized bodies than in others. Thus an elephant lives a century, whilst the ephemeron only exists a day; and in general all cold-blooded animals live longer than those with warm blood.
3. It frees bodies from the chemical laws of inanimate matter, and transfers the component parts of a body from the physical or chemical to the organic or living world.
4. It prevents putrefaction, for no organized body can putrefy unless deprived of life.

Humboldt is of opinion, that the degree of vitality depends upon the reciprocal balance of the chemical affinities of all the elementary parts of which an animal is composed.

Davy considers life as a perpetual series of peculiar corporeal changes, and the living body as the being in which these changes take place. They are consequently found to be continually varying: and since all organic sen-

sitive beings are unable to exist without light and oxygen, he looks upon these two, under the name of phosoxygen, as essential to existence.

Dr. Ferriar
opposes the
living prin-
ple.

Dr. Ferriar, in his observations concerning the vital principle, thinks that some direct arguments may be brought against the general supposition of an independent living principle. These arguments he divides into two kinds, viz. refutations of the general proofs offered in support of the vital principle; and instances of the direct influence of the mind and brain over what is termed the independent living principle. The great proofs for the support of a vital principle are, the contraction of muscles separated from the body on the application of stimulants; the performance of the vital and involuntary motions without any exertion or even consciousness of the mind, and the birth of full-grown foetuses destitute of a brain. In all these cases, something is alleged to operate, independently of the mind, in producing muscular motion.

Dr. Ferriar, in answer to the first argument drawn from the contraction of separated muscles, affirms, it may be said, 1. That the power of contraction in a separated muscle is lost before putrefaction takes place, *i. e.* before the destruction of it's texture; but if it's vitality depended on it's texture this ought not to happen. 2. The power of contraction in a separated muscle is strongest upon it's first separation, and becomes weaker by degrees: therefore the contracting power appears to have been derived from some source from which it is detached by the excision of the part. 3. Irritation of the medulla oblongata, or of the nerves supplying particular muscles, occasions stronger contractions than irritation of the muscles themselves; and Dr. Whytt furnishes an experiment on a frog, directly proving that the action of separated muscles depends upon the nervous energy. 4. Dr. Haller himself is obliged to make a concession on this subject sufficient to

destroy his favourite hypothesis of the *vis infinita*. 5. When a paralytic limb is convulsed by the electric shock, the motion never takes place without the patient's consciousness. In this case there is no distinction between the vital principle and that exertion which in voluntary motion is always attributed to the mind.

In answer to the second argument in favour of a vital principle, drawn from the performance of the vital and other involuntary motions, Dr. Ferriar contents himself with only observing, that allowing the organs of those motions to be supplied with nervous energy, their motions may be very well accounted for by the stimulus of their contained fluids.

The force of the third argument, drawn from the want of a brain in full-grown fœtuses, is taken off by Dr. Whytt, who remarks, that as the heart is sometimes wanting in full-grown fetuses, the argument would equally prove that the heart is not necessary for the continuance of circulation, as that the brain is not necessary to the support of the system. Accordingly, fetuses born without a brain do not in general survive birth.

Besides the general supposition of an independent living principle, an inference has been drawn from facts, of a nervous energy independent of the brain. By this term is meant, that condition derived from the brain to different parts of the body, by means of which they become capable of motion. To show by direct proof that there is no independent vital principle, Dr. Ferriar observes, 1. That it is justly urged by Dr. Monro against the doctrine of the *vis infinita*, that there is too much design in the actions of different muscles, affected by different stimuli, to be the effect of mere mechanism. Thus, when the hand or foot is burnt, or otherwise suddenly injured, the muscles on the part immediately stimulated are not thrown into action, nor the muscles on the side irritated, but their

antagonists contract immediately and strongly. Now, if the instantaneous action be in this case chiefly produced by an effort of the mind, the supposition of a distinct vital principle is superfluous : if it be said to be produced by a living power independent of the mind, then there must be a rational power in the body, independent of the mind; which is absurd. 2. The state of the vital and involuntary motions is considerably affected by the state of the mind, which equally disproves the existence of a separate vital principle, and proves the dependence of the nervous energy upon the brain. 3. Madness, it is well known, is frequently produced by causes purely mental, and in persons apparently in good health; and as the patient's sensibility to very powerful stimuli is much diminished in maniacal cases, they afford another proof of the subordination of the nervous energy. 4. It has been observed, that in paralytic cases motion is frequently destroyed, while sense remains. As the cause of palsy almost always resides in the brain, this fact appears equally inexplicable on the opinion of a distinct living principle, or of a nervous energy independent of the brain. 5. When nerves are regenerated after being cut through, sensation and voluntary motion are not always restored to the parts beneath the division: the restoration was never made in Dr. Monro's experiments. But on the supposition of a distinct nervous power, the nerve, after it's reunion, ought to resume all it's offices. 6. Dr. Whytt asserts, that when the spinal marrow of a frog is destroyed, after decollation, no contraction can be excited in the limbs by cutting or tearing the muscles. Such are the facts and arguments which Dr. Ferriar brings against the opinion of a distinct living principle; and he thinks that their investigation appears to lead us back to the brain as the source of sensibility and irritability.

Dr. Rush.

The last opinion which has been given of the principle

of life is that of Dr. Rush. He includes in animal life three properties, as applied to the human body; viz. *motion*, *sensation*, and *thought*, and these, when united, compose perfect life. It may exist without thought or sensation, but neither sensation nor thought can exist without motion. He affirms, that the lowest degree of life exists in the absence even of motion. He first considers animal life as it appears in the waking and sleeping states in a healthy adult, and afterwards inquires into the modification of it's causes, in the foetal infant, youthful and middle states of life, in certain diseases, in different states of society and in different animals, and lays down the following propositions :

1. Every part of the human body, the nails and hair excepted, is endued with sensibility or excitability, or with both.

2. The whole body is so formed and connected, that impressions made in the healthy state upon one part excite motion or sensation, or both, in every other part of the body.

3. Life is the *effect* of certain stimuli acting upon the sensibility and excitability, which are extended in different degrees to every external and internal part of the body; and these stimuli are as necessary to it's existence as air is to flame.

That animal life is a forced state was first delivered by Dr. Cullen, although he afterwards retracted it. He affirmed that the human body was not an automaton or self-moving machine, but kept alive, and in motion, by the constant action of stimuli upon it. Dr. Brown enlarged upon this, and formed a beautiful theory of excitability and excitement : and Dr. Rush endeavours to establish this discovery of life being a forced state; and he continues to observe, that the action of the brain, the diastole and systole of the heart, the pulsation of the arteries,

the contraction of the muscles, the peristaltic motion of the bowels, the absorbing power of the lymphatics, secretion, excretion, hearing, seeing, smelling, taste, and the sense of touch, even *thought* itself, are all the effects of stimuli acting upon the organs of sense and motion. These have been divided into external and internal.

1. The external are light, sound, odours, air, heat, exercise, and the pleasures of the senses.

2. The internal stimuli are food, drinks, chyle, blood, tension of the glands which contain secreted liquors, and the exercise of the faculties of the mind.

Life therefore (according to the hypothesis of Rush), even thought itself, is merely a quality residing in the component parts of a material system, dependent upon a peculiar organization, by which it is enabled to act, or in some way to move, on being stimulated or excited. Hence life can never be inherent in a simple uncompounded substance, nor in a particle of animal matter; and if the stimulus be withheld from a living system beyond a given time, all motion, sensation, and thought, must necessarily be extinguished.

He then inquires into the state of animal life in sleep, in the foetus, in infants, in youth and middle life, in old age, in persons who are blind, deaf and dumb, in idiots, in those under the effects of long fasting, and in those supposed to be dead, from drowning, freezing, and other causes. He afterwards takes a view of the state of animal life among the different inhabitants of the globe, as varied by civilization, diet, situation, and climate. He accounts for the influence of certain mental stimuli, which act nearly alike upon the individuals of all nations; of the causes of life in all the different classes of animals; of the causes of life in vegetables; of the causes of death; and lastly, he draws his conclusions from the doctrine of animal life being the effect of impressions upon the body.

Irritability.—Whatever motion there is in the animal body, it is all brought about by the muscular fibre; and since the connection of this fibre with oxygen is necessary, in order that it shall preserve it's irritable or contracting power, physiologists have endeavoured to investigate what may be the nature and origin of irritability itself.

Glisson is said to be the first discoverer of the irritable principle in the solid fibre, and this was afterwards enlarged upon by Haller, who found by a variety of experiments that the irritability of muscles remains a long time after their connection with the brain is destroyed. He gave it the name of *vis insita*. Fothergill, in his *Hints on Animation*, published in 1783, considers oxygen as the proximate cause of irritability; and Girtanner looks upon himself to be the discoverer of the same principle in the fluids of the body; and it is to this celebrated physiologist, and to Humboldt, that we are indebted for the most curious observations on this principle.

According to Girtanner, who has made a number of ~~Girtanner's~~ experiments on the subject, irritability is the principle of life in organized nature, and oxygen is the principle of irritability. His opinion is, that the irritable fibre, improperly called the muscular fibre, is universally expanded throughout all organized nature. It is on this that organic motion, sensation, and even life depends. He affirms that this irritable fibre is the same in all parts, and subject to the same laws; that the fluids of animals are endued with irritability as well as the solids, their irritability consisting in their coagulability, which is subject to the same laws as that of the fibre; that the degree of irritability of the solids and fluids is continually changing, and is different, according to the age and regimen of the same animal, according to the sex, organization, and size of the individual; that the state of health, or the tone of the fibre, consists in a certain quantity of the irritable

principle necessary to it's preservation. To maintain this state, it is necessary the action of the stimulus be sufficiently strong to deprive the fibre of the surplus of the irritable principle which the lungs and the circulation of the fluids continually furnish. When the irritability is totally destroyed, the fibre is in a state of gangrene; it changes it's colour, becomes livid or black, and is then subject to the laws of unorganized matter. That the irritable fibre, from the first moment of it's existence to that of it's dissolution, being constantly surrounded by bodies that act on it by stimulating it, and upon which it reacts by it's contraction, it follows, that during life the irritable fibre is in a continual action; that life consists in action, and is not a passive state, as some authors have advanced. According to the experiments of this physician, poisons act on the blood, as was before observed by Fontana, by depriving it of the principle of irritability, or of it's oxygen.

He then attempts to prove that it is to the oxygen, distributed to all parts of the system by means of the circulation of the blood, that the irritability and the life of organized bodies are owing. The proofs of which are,

1. The irritability of organized bodies is always in a direct ratio to the quantity of oxygen they contain.
2. Every thing that augments the quantity of oxygen in organized bodies augments at the same time their irritability.
3. Every thing that diminishes the quantity of oxygen diminishes likewise their irritability.

He distinguishes the organized fibre by three different states:

1. A state of health, or the *tone* of the fibre, in which the oxygen exists in it's proper quantity.
2. A state of *accumulation*, in which the fibre is surcharged with the oxygen or irritable principle.
3. A state of *exhaustion*, in which the fibre is more or less deprived of it.

Helikewise arranges all substances, that are capable of coming into contact with the irritable fibre, into three classes.

The first comprehends those substances that have the same degree of affinity for the irritable principle or oxygen, as the organized fibre itself; hence the substances produce no effect upon it.

The second comprehends those substances that have a less degree of affinity for oxygen than the organized fibre has: hence these, when they come into contact with it, surcharge it with oxygen, and produce a state of *accumulation*. They are called negative stimuli.

The third comprehends substances for which oxygen has a greater affinity than it has for the organized fibre. These therefore deprive the fibre of it's oxygen, and produce a state of *exhaustion*. They are called positive stimuli.

It is a fact well known, that the affinity of different substances differs considerably, according to the degree of temperature. The same difference, according to this physician, takes place with the organized fibre; hence, in speaking of the affinities of the irritable fibre in general, he means the temperature to be that of the blood in warm-blooded animals. Having made this observation, his arrangement of different substances is as follows:

In the first class he arranges all organized or living substances, which produce no effect upon the irritable fibre as long as their degree of temperature is the same as that of the fibre with which they come into contact.

In the second class (negative stimuli) he arranges some of the most fatal poisons. And it is on this account that the oxygenated muriatic acid is so deadly a poison to all organized bodies. It destroys them by the surcharge of irritability, or by superoxygenating them; and the consequence is, it is changed into common muriatic acid. Arsenic in it's metallic state has no effect; but the white oxyd

of this metal is one of the most excruciating and terrible poisons. The oxygenated metallic salts, as corrosive sublimate, or oxygenated muriat of mercury and butter of antimony, produce the same effects. Also the oxyds of silver and mercury produce more or less effects on the organized fibre, according to the quantity of oxygen they contain. The black oxyd of mercury, or *Æthiops mineral*, produces little or no action; whilst the red oxyd of the same metal produces the most terrible effects, and destroys organized bodies in a very short time. The action of the sulphats of tin and lead, and the acetates of lead and copper, is the same on the organized fibre.

He asserts that the animal as well as the vegetable organized fibre decomposes the water with which it comes into contact; that the greatest part of the water we drink is decomposed, then recomposed; that it is another method which nature makes use of to furnish organized bodies with the oxygen necessary to preserve their life and irritability. Hunger he looks upon as the consequence of accumulated irritability in the system; and for a substance to be nourishing, it is necessary for it to be a positive stimulus, *i. e.* it must have a great affinity for the oxygen with which the system is overloaded, by which it gives tone to the fibre, and stops the disagreeable sensation of hunger. Different substances, therefore, are only nourishing in proportion to their affinity for oxygen. It is on this account that living animal substances, as oysters, afford little or no nourishment, because, being already saturated with oxygen, they cannot combine with it; and hence the well-known observation, that oysters increase the appetite. Likewise animal jellies, fruits and vegetables, in general, nourish very little, or not at all. The flesh of newly-killed animals is not so nourishing as that kept for some time, and when raw is less so than roasted. From this arises all the art of the cook, which only consists in de-

priving the flesh of it's oxygen by different stimulating substances, such as heat, oils, sugar, alcohol, and other substances that have a great affinity to oxygen, and are very nourishing. In the East-Indies, millions nourish themselves by eating small quantities of opium when their crops of rice fail.

Thirst is a state of the system opposite to that of hunger; it is a sensation that indicates an exhaustion or want of oxygen. Water therefore, on being decomposed, as it comes into contact with the fibre, gives up it's oxygen to stop this disagreeable sensation. The same happens with vegetable acids, which are always decomposed in the stomachs of animals. If these acids are the best remedies against the effects of narcotic poisons, it is owing to their giving up the oxygen, on decomposition, to the fibre which these poisons have deprived of it. Hence vinegar cures the effects of opium and drunkenness, which is likewise effected by a large quantity of water. The freshness of the air after rain arises from the aqueous vapours coming into contact with our bodies, and restoring to them their lost oxygen. That singular insect the rotifer may be revived, after having been perfectly dried, by moistening it with water, which, on being decomposed, restores to it it's oxygen, and consequently it's irritability, of which the stimulus of heat had deprived it.

In the third class (positive stimuli) he arranges alcohol, sulphuric æther, opium, and other narcotics; oil of laurel, and oils in general; fat, sugar, &c. All the substances are combustible; *i. e.* they have a great affinity to oxygen; and it is by the same property they deprive the organized fibre of it's irritability, by uniting with the oxygen they contain. Amongst the positive stimuli that produce the most terrible effects are those of the putrid fever or plague, and of mephitic gas, which exhales from putrid animal

substances where the common air is not able to penetrate, as in tombs. The affinity of mephitic gas for oxygen is so great, that as soon as it comes into contact with the organized fibre it deprives it of all its oxygen, and produces death, which is sometimes immediately. The best way therefore to prevent the effects of this gas, is to detonate nitre on burning coals. The oxygen of the nitre combines with the gas, and renders it inert; and hence the use of respiring oxygen gas by those who are suffocated by it, and the freshness, as they express, which it affords.

Humboldt.

Humboldt, who has written an ingenious treatise on the nature and properties of the Galvanic fluid, looks upon irritability to be the common foundation of all vital action; and that it depends upon the property of the elementary parts of the muscular fibre to change their relative situation on the approach of a stronger or weaker stimulus, whilst in the sensible fibre of the nerve a fluid is accumulated called the Galvanic fluid; and he likewise asserts, that by means of this Galvanic fluid the state of the irritable capacity of a nerve or muscle may be ascertained, for which experiment a metallic stimulus, composed of zinc and silver, is necessary. According to this chemical physiologist, many of the opinions of Girtanner on the subject of irritability are erroneous; for, from various experiments, not only the irritability of the muscular fibre is to be increased by substances that contain no oxygen, but he found that a fluid containing no oxygen increases the irritability of the fibre more than any other known irritable means. Thus, if two organs of equal irritability be dipped in an alkaline solution, and in oxydated muriatic acid, the first will become irritated to powerful motion, whilst the other remains motionless; but according to the theory of oxygen, as a material principle of irritability, the contrary might be expected. Similar appearances take

place when alcohol, musk, camphor, tartar emetic, and muriated barytes, are used ; substances supposed to contain little or no oxygen.

With respect to bodies that increase or diminish irritability, he found,

1st. That all bodies containing oxygen increased or *augmented* the irritability of the nerves, such as the oxygenated muriatic acid, oxyd of arsenic, &c.

2d. That all bodies which absorb oxygen diminish or *lessen* this irritability ; such as the sulphuret of potash, solution of potash, nitrous gas, &c.

With respect to the *first*, if a large nerve be laid bare, as the crural, and if it be touched with substances containing oxygen, as the acids, it shows an irritability. The same takes place with very irritable muscles ; as the heart of a frog, when it's motion begins to diminish, by being plunged into an acid liquor, such as the oxygenated muriatic acid, has it's irritability restored to it.

With respect to the *second*. If this heart, however, remains too long in the acid, it's irritability is too much increased, by receiving too great a quantity of oxygen, and the motions cease. To make them therefore reappear, substances must be employed that can absorb this excess of oxygen, such as the sulphurets of potash, alkalis, &c. Thus, by moistening the heart by the sulphuret of potash, it's motions recommence. But the absorption of oxygen soon takes away all irritability : hence the motions cease again ; and, to make them reappear, the oxygen must be rendered to it again, by dipping it in the oxygenated muriatic acid.

He found that heat, alcohol, &c. equally reanimate the actions of the heart ; that the arterial blood produces the same effect, from it's containing oxygen, but not the venous blood. If the nerve of a part be tied, it loses it's irritability ; and the same happens if the artery be tied,

which carries the blood to it, as Haller has proved. The explanation this chemical physiologist gives of these facts is the following. He lays down three principles as necessary to excite the irritability.

1. *Oxygen*, which forms combinations with different acidifiable bases.

2. The *acidifiable bases* of the fibre with which the oxygen may combine. These acidifiable bases are, *carbon*, with which it forms carbonic acid, or oxyd of carbon; *hydrogen*, with which it forms water, or oxyd of hydrogen; *azot*, with which it forms oxyd of azot; *phosphorus*, with which it forms oxyd of phosphorus.

3. The *Galvanic fluid*.

These combinations, however, of oxygen with the acidifiable bases of the fibre cannot take place alone, the same as azot and oxygen mixed together do not produce nitric acid; but if the electric spark is made to pass through this mixture, the azot and oxygen combine, and the product is the nitric acid.

The Galvanic fluid produces, according to Humboldt, the same effect in the animal economy as the electric fluid in the mixture of azot and oxygen. It is this Galvanic fluid that, being conveyed by the nerves, brings about the combinations of the oxygen with the different acidifiable bases of the fibre; but when the nerve of a part is tied, it prevents the fluid from passing, which explains the reason of the irritability being destroyed.

The oxygen necessary for these unions is carried by the arterial blood in the course of circulation; and the acidifiable bases which are to unite with it are found to be already present in the fibre.

He found that every thing that augments too much the quantity of the acidifiable bases diminishes the irritability, and that every thing that increases too much the quantity of oxygen likewise diminishes it; and he thinks it very

probable that the same takes place with respect to the proportion of the Galvanic fluid.

It is therefore only in a just equilibrium of these principles that the necessary irritability of the parts consists; and the manner of it's operation this physiologist thinks may be conceived in the following way;

Suppose a fibre to be composed of the following particles *oooooo*, which are acidifiable bases, azot, hydrogen, carbon, phosphorus; the arterial blood then carries the oxygen to them, and the Galvanic fluid, conveyed by the nerves, making a discharge into the muscles, the acidifiable bases combine by this means, and they approach each other from their affinity becoming stronger, and the fibre is then shortened and contracted. In order to conceive the manner of the discharge in the internal part of the body, it is necessary to call to mind the manner of it's action externally.

For instance, let the nerve be *apm*, which is distributed in the muscle *oo*. The portion *m* of the nerve which is distributed in the muscle *oo* communicates to it a portion of it's Galvanic fluid; whilst the portion *pa* supposed to be detached from the muscle, and surrounded by air, which is not a conductor of this fluid, preserves it wholly. This portion *pa* contains, then, more Galvanic fluid than the muscle *o*. If, therefore, these two portions be directly put into contact, there will immediately be a discharge of the Galvanic fluid, which will pass from the nerve *a* into the muscle *o*.

The irritability may be likewise excited by establishing a communication between the nerve and the muscles by means of animal substances, as conductors, such as pieces of flesh or of nerve; also by placing a homogeneous metal, moistened on one side with an evaporable fluid, as water, between them.

It is the same with respect to muscular motion internally.

In a state of repose, the nerve being inserted in the muscles, the ^{gastric} fluid is put into an equilibrium in the organs that touch each other. The spontaneous motion is made by a surcharge of Galvanic fluid into the nerve. It appears that, the instant we wish to make a motion, the Galvanic fluid produced in the brain is carried in mass towards the part that ought to move, and surcharges the nervous fibres. A discharge from the nerve is then made into the muscles. The particles of these last, animated by increased affinities, approach each other, and it is this that constitutes the phænomena of contraction. The acidifiable elements, azot, hydrogen, carbon, and phosphorus, of which the muscular fibre is composed, combine amongst themselves, and with the oxygen of the arterial blood. Muscular motion, therefore, is productive of an aqueous fluid, as sweat, carbonic acid, nitric acid, oxyd of phosphorus, ammonia, soda. The Galvanic fluid being decomposed, or rendered latent by contraction, and the chemical phænomena that accompany it, the particles of the muscle reenter the sphere of their primitive attraction.

If the Galvanic fluid is carried away without the direction of the will (as is the case in diseases), and in too great quantity to one part, it gives rise to spasm and convulsion, which last has been put a stop to by the touch of metallic substances, which, being conductors of the Galvanic fluid, dissipate it. It is upon this principle, according to Humboldt, that Perkinsism is founded, or the method of curing diseases by metallic points. Dr. Rash of Copenhagen has published a book on this subject. The manner of using them is to present them to the diseased part, and relief is said to have been the consequence. The metallic points are commonly made of steel or silver, and are used in different manners. If by these the patient has in reality been relieved, it may be supposed to have arisen from diminishing or increasing the Galvanic fluid in the

part relieved; and it is perhaps on the same principles that magnetic plates have produced the good effects on applying them in the same manner to the diseased part, if it be true that cures have been effected by them.

Muscular motion, from what has been said, always supposes an abundant emission of the Galvanic fluid, and the same is the case with all the other functions. Thus digestion only operates by the Galvanic fluid, which renders the gastric powers active. Thought also equally requires the Galvanic fluid, which is conveyed to the place where it is to be put into execution: hence, in the time of digestion, it is to be supposed that thought either cannot take place, or that it should turn the Galvanic fluid elsewhere, and the digestion be disturbed. And as thought likewise requires a great deal of Galvanic fluid in the thinking organ, it is necessary that all the other motions, except the vital, be suspended, or *thought* cannot be made freely.

On this hypothesis, therefore, the different animal functions are a series of continual combinations made in the body.

The chief principles of the animal fibre, according to the ingenious philosopher Davy, appear to be nitrogen, Davy. hydrogen, carbon, oxygen, and light. He thinks the immediate cause of irritable action to be most probably the combination of the oxygen with the hydrogen and carbon forming water and carbonic acid, and liberating the azot and electric fluid; since it is certain that water and carbonic acid are liberated during muscular action; and probably azot, and light in it's condensed state electric fluid; as it is well known that the torpedo and some other animals give out the electric fluid during animal action. He thinks that in man the quantity is probably too small, and too slowly liberated, to be ascertainable. He looks upon the laws of mind to be most probably not different from the laws of corporeal motion; that every change in

our sensations must be accompanied with some correspondent change in the organic matter of the body ; but these changes an extensive and philosophic chemistry must enable us to find out ; that, by the discovery of them, we should be informed of the laws of our existence, and probably enabled in a great measure to destroy our pains and increase our pleasures. Thus would the science of chemistry become the most sublime and important of all.

Traëtatus de Naturâ Substantiæ energeticâ, feu de Vitæ Naturâ, à Francisco Glissonid. London, 1672.—*The Connexion of Life with Respiration, &c.* by Edmund Goodwyn, M. D. p. 99. London, 1788.—*Mémoire sur l'Irritabilité, considérée comme Principe de Vie dans la Nature organisée, par M. Girtanner.*—*Journ. de Phys.* 1790.—*Versuch über die Lebenskraft, von J. D. Brandis.* Hanover, 1795.—*De la Metherie, in his Journal de Physique, p. 32. tom. 48.* Paris, 1799.—*Hufeland die Kunst des Menschliche Leben zu verlangern.* Jena, 1798.—*Versuche, &c. nebst vermuthungen über den Chemischen Proceß des Lebens, &c. von F. Alex. von Humboldt.* 2 vols. Berlin, 1799.—*Observations concerning the Vital Principle, by John Ferriar, M. D.* Manchester Memoirs, vol. iii. p. 216.—*Three Lectures upon Animal Life, by Benjamin Rush, M. D.* Philadelphia, 1799.

Respiration. *Respiration.*—The process which nature employs to oxygenate the blood, by means of the lungs, is called respiration ; a function not only enjoyed by the animal, but also in some degree by the vegetable creation ; and so essential is it to life, that wherever vital organization is found to exist there is no exception to the general rule.

Composed
of two actions,
inspiration and
expiration.

This function is composed of two actions; the dilatation of the thorax, by which a quantity of air is received into the lungs ; and it's contraction, by which the air is expelled from them : and these two actions take place alternately. According to the present theory of respiration, inspiration

is the means of communicating the oxygen of the air to the blood, which, in consequence, is changed from a dark to a fluid red colour, and there is an extrication of caloric producing animal heat. Expiration, on the contrary, is found to convey what might be hurtful, such as fixed air and aqueous vapour out of the lungs.

In all animated beings, the final intention of this function is the same; but on examining the parts in different classes of animals, the organs by which respiration is produced are exceedingly varied. On taking, however, a general view, perhaps the most simple division of the respiratory organs will be the following.

1. Lungs, as in man; quadrupeds of the two orders; Division of the organs. birds; and the cetaceous class.

2. Gills, as in fishes.

3. Stigmata, or holes in different parts of the body, as in insects.

Of these three species there are great varieties of form, but the office in which they are employed is the same; thus the varieties of the first and last species of respiratory organs communicate the oxygen to the blood by the atmosphere, whilst those of the second species communicate it by water.

There are two observations which have been made upon the respiratory organs of animals.

I. The quantity of blood is found to be in a given ratio to the perfection of their respiration, whilst the difference of the circulatory organ or heart is always in a ratio to that observed in the respiratory organ; both of these functions undergoing, in some measure, a gradual degeneration in the different classes of animals, and the animal heat keeps the same ratio; hence a scale may be formed of these gradations in the following manner.

Observations on the different organs of respiration.

1. Quadrupeds. 2. Cetacea. 3. Birds.	4. Ovip. Quad. 5. Serpents 6. Fishes.	7. Insects. 8. Worms.
Blood in large quantity, and hot.	Blood in small quantity, and nearly cold.	A white liquor instead of blood.
Two ventricles in the heart.	One ventricle.	Heart of different forms, or unknown.
Respire by lungs, and frequently.	Respire at long intervals; some by lungs, others by gills in their imperfect state, and others always by gills.	Respire by stigmata, or by unknown means.

1. Of quadrupeds, cetacea, and birds, the last have the most extensive lungs, and they are found to exceed the two other orders in possessing a higher temperature; but this perfection of their respiration, as it has been called, has it's disadvantages; and they are the first to feel the bad effects of noxious airs, which have been proved by experiment to be sooner fatal to them than to the others.

2. Oviparous quadrupeds, serpents, and fishes, have their blood still less warm, their lungs smaller; and whether gills or lungs, a smaller quantity of oxygen is of course communicated to their blood, which is less in quantity than in the before-mentioned orders. Of the oviparous, who can stop their respiration for forty or fifty minutes, and upon which animals experiments have been made, they are found to resist even carbonic acid gas for a great length of time, and do not die in less than fifty minutes; a small portion of blood only passes through their lungs, the rest being conveyed immediately from one ventricle to another. Fishes have likewise less blood in proportion to their bulk than quadrupeds, which agrees very well with their imperfect respiratory organs. In these, however, there is great variety. Thus the cartilaginous species of fishes that have their respiratory organs more extended than others have likewise a larger proportion of blood. The pike, also, the organs of which are more complete than those of the

carp, contains more blood, but cannot live so long out of water; and the carp, respiring in a more perfect manner than the eel, is likewise furnished with more blood.

3. With respect to insects the difference is more striking; their heart is membranous, scarcely susceptible of motion, and instead of lungs they have only vessels distributed to different parts of the body. Their blood, if it can be so called, has not that red colour which characterizes that fluid in other animals; but they are very tenacious of life, and are not easily destroyed on respiring noxious airs. Thus, according to Young, animals of this order, as wasps, &c. when exposed to carbonic acid gas, although they become torpid at first, soon recovered from their lethargy, and appeared to sustain the effects of the air without any inconvenience.

II. The second observation which has been made respecting the organs of respiration is, that the more perfect respiration is, the more are it's organs concealed. Thus birds, whose respiration is so perfect, at least according to Brouffonet, have the air conducted even into the cavities of the greater part of their bones; and consequently their organs are more internally situate than those of quadrupeds, in which the lungs only, defended by the thorax, are more concealed than those of the oviparous tribes, the respiratory organs of which are placed externally during the first period of their life, and internally the remaining part, when their metamorphosis obliges them to breathe the atmospheric air. The organs of fishes, or their gills, are nearly uncovered, and may be seen without destroying or taking away any part; but as they breathe in a more perfect manner than the mollusca and aquatic shell-fish, their organs are even more concealed; in which last they are most commonly situate externally, and are perfectly exposed. It is in these that this function appears to be nearly effaced; and, in order to dis-

Knowledge
of the an-
cients on
this subject.

cover it, we can, in general, be guided only by analogy. In the vegetable tribes the leaves are their respiratory organs, and are only of use during a part of the year : in winter they are deprived of them. The absolute necessity of breathing must certainly have been known to the earliest ages of antiquity : it's great importance seems even to have been acknowledged by Moses :—" And the Lord God formed man of the dust of the ground, and *breathed into his nostrils the breath of life, and man became a living soul.*" Gen. ii. 7.—But the discovery of it's use, and more particularly the process which is carried on in the system during respiration, is, like most other discoveries of the first magnitude, only of modern date ; nor could the ancients have been capable of forming any tolerably precise idea of the subject, from their ignorance of the nature of the atmosphere itself. We are informed by Diodorus Siculus, it was an opinion amongst the ancient Egyptians, that the atmosphere was incorruptible ; that it was of such extent as to reach even unto Heaven ; that it's most important office was in concurring towards the generation of all animals ; and it appears, from the epithet of Glaukopis, which they gave to the goddess of the air, that they considered the blue firmament as peculiar to it's colour. This opinion of air being the principle of all bodies was supported by many Greek philosophers, such as Anaximenes, Diogenes of Apollonia, and Archelaus the master of Socrates. From the nature of air being so little understood, it cannot be supposed that their notion of respiration could be very exact ; and we are informed that Empedocles was of opinion it was brought about principally by the nose, and that it was determined by the void, which the motion of the blood alternately operated in a part of the veins.

Notwithstanding the imperfect knowledge of the ancients respecting this function, they knew very well how

indispensable the necessity of air was to the support of life, that neither animal nor plant could live without it. They knew that when animals had remained a certain time in a given quantity of atmospherical air, they began to languish, and become to all appearance sleepy; that this sleep was at first peaceable, but was soon followed by great agitation; that respiration then became difficult and precipitate, and that death succeeded in convulsions. These Aristotle. facts were well known to Aristotle, Eristratus, and Are-tæus. Hippocrates reckoned air a species of aliment that Hippocra- was necessary to the animal system. The opinion, how- tes. ever, which appears to have prevailed the longest and most universally amongst the ancients, was, that respiration is chiefly intended to temper the blood, and carry off the fuliginous vapours with which it is loaded by the vital fire constantly kept up in the heart. This hypothesis was strongly supported by Galen. Four ages after Aristotle Galen. we find the knowledge of this subject scarcely any further advanced. Pliny calls the air the vital spirit, and Pliny. Cicero affirms that the heart imbibes a spirit from the air. Cicero. Among the moderns, Descartes revived the hypothesis Descartes. which Galen had so well supported, and maintained the same vital fire in the heart, supposing that air was necessary to cool and condense the blood. Borelli reckons Borelli. the great use of respiration to consist in the admission and mixture of air with the blood, in order to inform those elastic globules of which it is composed, to give it it's florid redness, and to prepare it for many purposes of the animal œconomy. Bathier was of opinion that, during respira- Bathier. tion, the more subtile and elastic particles of the air were imbibed, and the cruder part expelled through the pores of the pulmonary arteries into the trachea. Van Hel- Van Hel- mont ascribed the volatility of the fixed elements in the mont. food to this air; and Stephenson thought that the air which had circulated in the blood, and which had heated

Boyle.

it too much, was exhaled by the lungs. Boyle and others thought that the air itself is not admitted to the blood, but that some active, spirituous, and ethereal particles were communicated to it; that this vital spirit passes from the lungs to the heart and arteries, and at length becomes the animal spirits, which are, by this means, generated by the air. Those, on the contrary, who did not admit that the animal spirits are derived from the air, still say that some other *vital principle* comes from thence. This vital principle, imbibed from the air, Malpighi calls a saline vapour; Lister, an inflammable sulfureous spirit; Vieussens, a volatile acid salt, which keeps up the fermentation of the blood; and Bryan Robinson, that it is the ærial acid which preserves it from putrefaction, and gives strength to the animal fibres. Hence he supposes it is that we feel ourselves refreshed in cold air, as it abounds with a more acid quality. But of all the opinions that have been given respecting the function of respiration, the theory of Mayow is the most deserving of attention.

Mayow.

This celebrated philosopher lived about the middle of the 17th century. He was contemporary with Boyle, Lower, and Willis; and so acute was his observation of natural phenomena, and so just his judgment on the causes which produced them, that, with respect to respiration, Dr. Beddoes has very properly observed he has, in some measure, anticipated the discoveries of the present day. His works give an account of the use of the air in combustion and respiration, or it's diminution and absorption by them. They assert, in a very clear and positive manner, the absorption of one part of the air by the blood, which he calls the vital part, as well as the warmth of this fluid produced by this absorption, or by the presence of air in the lungs. Mayow has likewise shown that the red colour of the blood, and the change of the venous into arterial blood, depend entirely on the contact of the atmo-

spheric air; and had he known how to have extracted the vital air of the atmosphere from the substances that absorbed it, had he but known it's properties when in it's pure and isolated state, he would have established all the principles of the present theory of combustion, respiration, and the formation of acids, general ideas of which are to be found in his works.

It appears from these, that 120 years ago he had imagined an apparatus by which he could determine that the air was in part fixed, or diminished, and absorbed by combustion and respiration; that these two phenomena acted upon it in the same manner; and that there was only one part of the air, the most subtle and elastic, which may be called vital, and that served both for inflammation and respiration. "What confirms our hypothesis," says he, "is, that the air, on coming from the lungs of animals, is found diminished in it's elastic force on account of it's nitro-aerial principles being exhausted by respiration: these experiments will prove the last assertion. Attach a wet bladder to the circular edge of the orifice of a vessel, like a skin extended on a drum; place a small cupping-vessel containing a mouse upon this bladder, and load it with a weight to prevent the animal overthrowing it. A few instants afterward you will see the cup adhering strongly to the bladder, and this pushed into the vessel as if the flame had been under it. This phenomenon will take place whilst the animal still breathes. If you attempt to take away the cup, you will raise at the same time the bladder, which strongly adheres to it, and with it the vessel it covers, unless it be too heavy: and, in effect, a mouse put into a cupping-vessel, and applied to the skin, is able to supply, to a certain point, the flame which it is customary to produce in it. The result certainly is, that the elas-

“ticity of the air contained in the vessel has been diminished by the respiration of the animal, in such a manner as no longer to sustain the pressure of the atmosphere.

“To give a better conception of this result, we shall add another experiment analogous to it, which will serve to determine what fraction, what part of the air, deprived of it's vital particles by respiration, is diminished in it's volume. An animal is to be placed in an inverted glass, or suspended in a prison or grate at the top of a glass cucurbit : the orifice of the cucurbit is then placed in a jar, and plunged into water, in such a manner as this may rise to the same height as externally, which may be attained by the assistance of a crooked syphon already described : the exterior water is to be somewhat voided, so that the water in the cucurbit may be better seen ; the height of which is to be marked by a paper glued upon the outside of the vessel. The water soon rises in the cucurbit, and continues to rise by degrees, although the heat produced by the animal, and the exhalations produced from it's body, would seem to produce a contrary effect. In order to terminate the contraction the air in the vessel undergoes before it is become incapable of supporting the life of the animal, the following method may be employed : the space occupied by the air is to be measured at the moment the mouse is introduced, and afterward that to which it has been reduced after the suffocation of the animal, and the ascent of the water, which is done by the volume of water employed to fill these spaces : leaving the apparatus in the same state, the height of the first space above the second is then to be calculated, and the difference is the measure of the volume and of the elasticity diminished by the respiration of the animal. I am

“ assured by different experiments made with different
 “ animals, that the air loses about one fourteenth of it’s
 “ volume by respiration.

“ It is then very evident, that animals in respiring absorb
 “ certain vital and elastic particles from the air. There is
 “ no doubt but that there enters, by respiration, some-
 “ thing aerial into the blood of animals which is necessary
 “ to life. It is not only for the attrition of the blood that
 “ the lungs and their functions are destined, &c. nor is
 “ it certain whether this aerial principle is absorbed by
 “ the capillary tubes, or the extremities of the sanguineous
 “ vessels : but the air is not less deprived of it’s elasticity
 “ by respiration than by combustion ; and there is reason
 “ to believe that animals take particles of the same sort
 “ as fire does from the air, as the following experiment
 “ proves.

“ If an animal and a lamp be enclosed in a glass vessel
 “ which has no communication with the external air,
 “ which is easily done by inverting this vessel into water,
 “ the light will soon be extinguished, and the animal will
 “ not resist a long time this *cruel torch*, *tædæ ferali*. I
 “ have found by observation, that an animal enclosed in the
 “ same glass with a lamp does not breathe longer than
 “ half the time it would have done if alone : It is not the
 “ smoke which suffocates it ; for spirit of wine, that affords
 “ no smoke, produces the same effect : but the air, yield-
 “ ing it’s nitro-aerial particles to the flame, can no longer
 “ furnish the animal with them. This has no occasion
 “ for so many igneo-aerial particles as the lamp ; for the
 “ lungs, as it were, go in search of them to absorb them :
 “ as to the flame, it is necessary for them to be near it,
 “ present themselves, and be incessantly renewed : hence
 “ the animal exists some time after the extinction of the
 “ lamp, and when the aerial particles are almost entirely
 “ exhausted. It is on that account that the air in which

“ the animal is suffocated undergoes more than twice the
 “ diminution of that in which a candle is extinguished,
 “ as has been seen. I have tried in vain to light again, by
 “ the assistance of a burning glass, the combustible matter
 “ contained under the same vessel as the animal that had
 “ expired ; and although it is possible that the foggy season
 “ of the winter may have produced some incertitude in
 “ this experiment, it is not less probable that the air
 “ which is no longer proper to support the life of animals
 “ is no longer so to support flame, since more aerial par-
 “ ticles are necessary for the inflammation of the lamp
 “ than for respiration : it is however not to be concluded
 “ from hence that the mass of blood is in a real combus-
 “ tion.”

He also observes, that mice and birds placed towards
 the superior part of the cucurbit died sooner than those
 in the inferior part ; and that in the first case the water
 did not rise so high. He observes, that if two animals be
 put at the same time into the same vessel, the one in the
 top part and the other below, the first soon dies, and the
 other survives it for some time ; from which he concludes
 that the air, deprived of it's nitro-aërial particles, is be-
 come lighter, and that the part of it which still preserves
 them occupies the inferior part of the vessel. He says,
 therefore, that an animal which begins to suffer from
 want of air raises it's head towards the upper part of the
 vessel ; but finding itself more affected in this place, it im-
 mediately plunges it's head below again, and keeps it fixed
 at the bottom. He applies the same remark to a candle,
 which, when carried to the top of the vessel, is extin-
 guished much sooner than below, because the air be-
 comes incapable of supporting the flame ; and since it is
 become at the same time lighter than the atmospherical
 air, it is pushed towards the top of the cucurbit, and not
 permitted to depart ; which proves that the air is deprived

of certain solid and heavy particles by inflammation and respiration, since it acquires lightness on coming from the flame and the lungs.

He likewise obtained, without knowing it, nitrous air or gas (by the means of iron wire and the nitrous acid); and having observed the diminution of air by this gas, he with reason compares this effect to that produced by candles and respiration, fifty years before Hales had observed the same, and a century previous to the discovery of Priestley respecting nitrous air, and its property of forming nitrous acid with the vital air of the atmosphere. He is of opinion, that the nitro-aërial spirit is condensed in the same manner by the blood as by the iron-wire in the nitrous acid (by which he procured the gas), *i. e.* by fermentation: hence it is to the sanguineous fermentation that he attributes the same condensation in respiration. He thinks that the fermentation of the blood is produced by the condensation of the nitro-aërial spirit, and this condensation by the fermentation of the blood; for, the particles of this spirit once condensed, he admits their introduction into the mass of the blood; and to these he attributes its red colour, its heat, and fluidity. It is on this account, he says, that the blood is black in that part which does not touch the air, and very red in that part which is in contact with it; that the venous blood is black, and the arterial of a splendid red; that violent exercise heats, by multiplying the inspirations; that a person becomes warmer by voluntarily increasing his respiration; that the fevers of consumptive people arise from the force with which the pus of the lungs attracts and absorbs the nitro-aërial spirit, with which it produces a great fermentation; that, venous and arterial blood being placed under the vacuum of Boyle, the first only offers a few blebs, whilst the second is totally converted into foam. He adds, that this nitro-aërial spirit gives the red colour to

bodies in which it exists, as to the fuming spirit of nitre. He compares the heat produced by the condensation of this spirit in the lungs, with that produced by pyrites in effervescence; and he attributes the vitriolization to the same cause.

Such are the principal facts which Mayow delivered to posterity, at a time when the subjects on which he treated were little understood, and his experiments still less so, by the age he lived in. No philosopher, at the end of the last century, had given any theory of combustion and respiration, or any account of the analogy between these two natural phenomena; of the reciprocal influence between them and the air; and of the effects produced by this fluid compared with those of nitre on combustible bodies, with so much detail and sagacious ingenuity as this physician. His works form an epoch in the annals of respiration. In giving Mayow all the merit due to him, it appears, however, that although he had determined with great precision the use of the nitro-aërial spirit of the atmosphere to be to warm the blood and give it its brilliant red colour, he was ignorant whence these phenomena arose, and how the air contributed to it: and although these nitro-aërial and igneo-aërial particles may be looked upon as the vital air or oxygen gas of the moderns, he knew nothing of its properties, nor the change it underwent by the action of flame and respiration. These explanations were reserved for Priestley and Lavoisier.

Malpighi. Malpighi has been already mentioned. It was a received opinion, that one use of the lungs was to attenuate the blood; and, according to Malpighi, the different parts of the blood by this means become thoroughly mixed together; while others were of opinion, that the blood is condensed in the lungs; and others, that the globules and all the finer humours receive their configuration

there. Some, without considering the air as of any other use than to put the lungs in motion, thought that heat is produced in the lungs by the attrition of the blood in passing through them. The red colour of the blood has been thought by some to be caused by this attrition in the lungs; but Lower refuted this notion, chiefly by observing that the attrition of the blood is greater in the muscles, from which, however, it always returns black. Whytt thought there was something of a vital and stimulating nature derived from the air into the blood. Sir Isaac Newton imagined that the atmospheric air might communicate an acid vapour to the blood in the lungs, which was necessary to keep up the action of the heart. According to Boerhaave, air which has not been changed is deadly; not on account of heat, rarefaction, or density, but from some other *occult cause*. Lower. Newton. Boerhaave.

Dr. Hales, who, if we except Mayow, has thrown more light on the doctrine of air than any of his predecessors, was equally ignorant of the use of it in respiration, and seems to have adopted, at different times, different ideas of it. It appears, from various passages in his Statical Experiments, that he believed the red particles acquire considerable degrees of elastic vibrations, if not an electrical virtue, in passing through the lungs; “for (says he), while by the extraordinary frictions they undergo they are much heated and dilated, they are at the same time refrigerated and contracted by the fresh air that is continually taken into the lungs; for the coats of the vesicles are so extremely thin, that those two fluids are supposed to be 1-1000th part of an inch within contact of each other: so that, like blended liquors, they must needs have a considerable effect upon each other; the air in cooling the blood, and the blood in warming the air.” He is likewise of opinion, that the red colour of the globules intimates their abounding with sulphur; that the

air is rendered alkaline by breathing ; and that suffocation is owing to the collapsing of the minute vesicles of the lungs, in consequence of the confined air being deprived of elasticity, and the contraction occasioned by the stimulating sulphureous vapour. He says the venous blood is not florid ; which floridness in the arteries may be owing to the greater velocity with which it passes through the lungs than other parts of the body ; for blood agitated much in a closed vessel was observed to become very florid, even as much as arterial : but the great purpose of the lungs is to refrigerate the blood.

H. Her.

Haller, after giving the opinions of all that went before him, says that the use of the lungs is partly inhaling and partly exhaling ; that the lungs *inhale* both water and air, but that in them the air loses it's elastic property, so as to be easily soluble in water or vapour ; and he thinks it probable that the air serves as a cement to bind the earthy parts together. He does not doubt but that various other matters, miscible with water, are inhaled by the lungs ; and he thinks it not improbable but that the air may carry some electric virtue along with it. The principal *exhalation* of the lungs he thinks to be water, abounding with oily, volatile, and saline principles ; and these oily and foetid vapours, he thinks, are the *fuligines* of Galen and the ancients.

Cigna,

Cigna, in a work *De Respiratione*, takes it for granted that air which has been once respired becomes unfit for further respiration, because it is loaded with noxious vapours, to be known by their foetid smell. He says that air is diminished by respiration ; and that air which has been breathed suffocates by means of the irritation it occasions to the lungs, by which the bronchia, and the lungs themselves, are contracted so as to resist the entrance of the air ; and therefore that respired air is noxious on the same account as mephitic vapours, or those of burning sulphur :

that in frequently breathing the same air it becomes so loaded with these vapours as to excite a convulsion of the lungs, and thereby render them unfit for transmitting the blood. He supposes that air enters the pores of the blood, retaining it's elastic power; and that it continues at rest there, because it's endeavour to escape is counteracted by the equal pressure of the ambient medium. This air he thinks is introduced by the chyle, and never by the way of the lungs, 'except when, by some means or other, the equilibrium between the air in the blood and the external air is lost. If the external air be rarer than the internal, the air in the blood, expanding itself, will inflate the animal, and have the same effect as air introduced into the veins.

Upon the whole, he concludes that the principal use of air to the *blood* is to preserve the equilibrium with the external air, and to prevent the vessels from being rendered unfit to transmit the blood, on account of the external pressure; whereas, by means of the air they contain, the fluids move in their proper vessels as freely as in *vacuo*, and the membranes and viscera also easily slide over each other. With respect to the use of the lungs, since he imagined that air is not introduced into the blood by means of them, he thinks that because such lungs as those of men are given to the warmer animals only, the chief use of respiration is exhalation, and consequently the cooling of the blood.

On casting the eye over the variety of opinions which for so many centuries have taken place of each other respecting the use of respiration, it may appear somewhat extraordinary that no one should have been so fortunate, if we except Mayow, as to conjecture rightly; but this surprise will be diminished on considering, that, before any real light could be thrown on this obscure subject, it was necessary that the nature and component part of the atmo-

Discovery
of oxygen
gas in the
atmosphere.

sphere we breathe should be investigated and made known. Some chemical philosophers were engaged at the same time upon this interesting subject, and their labours upon the air and the different gases have been crowned with success. A pure ærial principle was found to exist in the air much about the same time by Dr. Priestley, who called it *dephlogisticated air*; by Scheele, who named it *empyreal air*; and by Lavoisier, who gave it the name of *highly respirable* or *vital air*: and as it was afterward found by the French chemists to be the acidifying principle to the basis of acids, they call it *oxygen*, or, in it's combination with caloric, *oxygen gas*. What therefore was only conjectured by Mayow to form a part of the atmosphere, has been proved, beyond a doubt, to be the great agent in the office of respiration; and as Boyle, Hales, Black, and Priestley, may be considered as the first who observed with accuracy that respiration exercises an evident action on the atmospheric air, that it diminishes it's volume and changes it's nature, and that, in a very short space of time, the fluid made use of by this function loses the property of supporting any longer the life of animals, a clue was presented to the chemical physiologist that would lead him to account for all these phenomena.

Stahl's
phlogiston.

At the time of the discovery of *oxygen*, as composing a part of the atmosphere, the prevalent doctrine was that of Stahl. Becher had imagined a substance to exist in inflammable bodies, which is the principle of inflammability, and which is called *phlogiston*; and the genius of Stahl had matured this into a theory, by which he accounted for almost every chemical phenomenon. The phlogistic fluid was either imbibed by or extricated from every thing. The sectaries of Stahl applied this doctrine to explain the effects of respiration; and they supposed that, during the action of this function, a certain quantity of phlogiston was exhaled from the blood as it passed through the lungs,

which they said phlogisticated the respired air in the same manner as they had admitted it's phlogification by combustion, the calcination of metals, and other processes which they called phlogistic.

Amongst these philosophers was Dr. Priestley. He ^{Dr. Priestley.} informs us, that the property in the air which contributes to the support of life, and the reason that air which has been much respired will no longer serve that purpose, were not discovered by any body; and they might have continued to elude all *direct investigation*, when they discovered themselves in the course of experiments upon airs which had at first quite another object. According to this philosopher, in the experiments it clearly appears, that respiration is a phlogistic process, affecting air in the very same manner as every other phlogistic process, such as putrefaction, the effervescence of iron filings and sulphur, or the calcination of metals, affects it, diminishing the quantity of it in a certain proportion, lessening it's specific gravity, and rendering it unfit for respiration or inflammation, but leaving it in a state capable of being restored to a tolerable degree of purity by agitation in water, &c. Having discovered this, he concluded that the use of the lungs is to carry off a putrid *effluvium*, or to discharge that phlogiston which had been taken into the system with the aliment, and was become, as it were, *effete*, the air that is respired serving as a *menstruum* for that purpose. He thinks the use of respiration is confined to the blood, in consequence of it's coming so nearly into contact with the air in the lungs, the blood appearing to be a fluid wonderfully formed to imbibe and part with that fluid called phlogiston, changing it's colour in consequence of being charged with it or freed from it, and affecting air in the very same manner, both out of the body and in the lungs, even when various substances are interposed which prevent it's coming into immediate contact with the air.

The black colour of blood Dr. Priestley accounts for as arising from imbibing phlogiston, as may be seen from his experiments quoted on the colour of blood; and when he had found how readily pieces of blood changed their colour according to the quality of the air to which they were exposed, the next thing was to examine the state of that air, to find what change had taken place in it; and as dephlogisticated air admits of a more sensible change of quality than common air, he gave it the preference, putting a piece of crassamentum, about the size of a walnut, into about five ounce measures of this air.

This process he continued twenty-four hours, changing the blood ten or twelve times; after which he found the air so far depraved, that whilst, at the beginning of the experiment, one measure of it and two of nitrous air occupied the space of no more than half a measure, the same mixtures afterwards occupied the space of a measure and a half. Now, since air is universally depraved by phlogiston, and in this sense by nothing else, he thinks it is evident that this black blood must have communicated phlogiston to the air, and of course its change of colour from black to a florid red must have arisen from this separation of phlogiston.

The next day, when of course the blood was nearer to a state of putrefaction, in which every kind of substance will injure respirable air, he put a quantity of red blood tinged in a few places with black, which he could not easily separate from it, to about the same quantity of the same dephlogisticated air, and suffered it to stand, without changing, for the same space of time; when it was so little injured that the measures above mentioned occupied the space of only two thirds of a measure.

That blood has a power of taking phlogiston from air, as well as imparting phlogiston to air, he satisfied

himself by exposing blood of a very beautiful florid colour to nitrous, inflammable, and phlogisticated airs. The two first kinds of air were considerably diminished by the process, which was continued two days, and the blood changed five or six times.

The nitrous air lost a great portion of it's power of diminishing, *i. e.* phlogisticating common air: for now two measures of common air and one of this occupied the space of two measures and a quarter, instead of one measure and three quarters.

The inflammable air, though still inflammable, was rendered in some degree wholesome by the process; being after this considerably diminished by nitrous air, which is a state to which it is brought by agitation in water, and which, continued longer, deprives it of it's inflammability likewise. Hence, in both these cases, the red blood, by becoming black, received phlogiston from these two kinds of air. As to phlogisticated air, Dr. Priestley only observed, that after a few hours exposure to red blood it was sensibly, but not much, diminished by nitrous air, which otherwise it would not have been in the least degree. This blood, however, was of the lightest colour, or the most free from phlogiston, of any he had seen: and he has tried the same thing, without success, with blood of a less florid colour, though as florid as the common air could make it. But as the proper function of the blood is not to receive (meeting with no phlogisticated air during circulation), but to communicate phlogiston to air, there is not the same reason to expect that air will be mended by red blood, as that it will be injured by black blood. Dr. Priestley had imagined that, since black blood contains more phlogiston than red blood, a similar difference would have appeared in the air produced from them, either by being simply dissolved in spirit of nitre, or when dried and made into a paste with this acid.

But the difference was too small to be sensible to this kind of test. He used blood from the vein of a sheep, and from it's carotid artery. The quantity of air from the paste was very great, and produced irregularly, as is the case when produced by a solution in spirit of nitre without drying. Half the produce was fixed air, and the rest phlogisticated, except that a candle burned in it with a lambent blue flame. From this experiment, however, it is evident that even the most florid blood contains a considerable quantity of phlogiston, for otherwise this air would have been dephlogisticated. He found great difference in the constitution of blood, with respect to it's property of being affected by the influence of the air, some becoming very soon of a light florid colour, and the stratum of this colour soon growing very thick: others, in the most favourable circumstances, continued much darker, and the lighter colour never penetrated far.

Being convinced afterwards of the reception of dephlogisticated air into the blood, besides the emission of phlogiston from it, Dr. Priestley wished to determine *how much* of the dephlogisticated air enters the blood, a part of it being employed in forming the *fixed air*, which is the product of respiration, by it's uniting with the phlogiston discharged from the blood.

To determine what proportion of dephlogisticated air, destroyed during respiration, is employed in forming fixed air, it was necessary to ascertain the proportion of dephlogisticated air and of phlogiston in the composition of fixed air. He therefore

Heated charcoal of copper in 41 oz. m. of dephlogisticated air, of the standard of 0.33, till it was reduced by washing in water to 8 oz. m. of the standard of 1.33. Again, he heated charcoal of copper in 40.5 oz. m. of dephlogisticated air, ft. 0.34, till it was reduced to 6 oz. m.

ft. 1.76; and in each there was a loss of 6 grs. of the charcoal of copper: so there cannot be more than 6 grs. of phlogiston in 33 oz. m. of fixed air; hence very little more than one fourth of the weight of fixed air is phlogiston.

He heated perfectly well burnt charcoal of wood in 60 oz. m. of common air, and found one-fifth of the remainder to be fixed air, the residuum, ft. 1.7. Lastly, he heated $8\frac{1}{4}$ grs. of perfect charcoal in 70 oz. m. of dephlogisticated air, ft. 0.46, when it still continued 70 oz. m.; but after washing in water it was reduced to 40 oz. m. ft. 0.6. and the charcoal then weighed $1\frac{1}{4}$ gr.: so that from these experiments with common charcoal, as well as from those with charcoal of copper, about one fourth of the weight of fixed air is phlogiston, and consequently the other three fourths are dephlogisticated air.

Dr. Priestley then wished to ascertain the quantity of fixed air formed in respiration from atmospherical and dephlogisticated airs, in order to determine if any part remained to enter the blood, after forming this fixed air.

For this purpose he breathed in 100 oz. m. of atmospherical air, ft. 1.02, till it was reduced to 71 oz. m., and by washing in water to 65 oz. m. ft. 1.45. The computations made as before, it will appear that, before the process, this air contained 67.4 oz. m. of phlogisticated air, and 32.6 oz. m. of dephlogisticated air; that after the process there remained 53.105 oz. m. of phlogisticated and 11.895 oz. m. of dephlogisticated air, and there were only 6 oz. m. of fixed air produced, for the quantity absorbed during the process could only have been very inconsiderable. It will therefore be evident, that in this experiment 20.7 oz. m. of dephlogisticated air, which would weigh 12.42 grs., disappeared: whereas all the fixed air that was found would only have weighed 4.4 grs.

and one fourth of this being phlogiston, the dephlogisticated air that entered it would have weighed only 3.3 grs. : consequently 9.12 grs. of it must have entered the blood ; which is three times as much as that which did not enter, but was employed in forming the fixed air in the lungs.

He breathed in 100 oz. m. of dephlogisticated air, ft. 1.0 till it was reduced to 58 oz. m., and by washing to 52 oz. m. ft. 1.75, with two equal quantities of nitrous air. The computations being made, it will appear, that before this process this air contained 66 oz. m. of phlogisticated and 34 oz. m. of dephlogisticated air ; and after the process there were 30.368 oz. m. of phlogisticated, and 21.632 oz. m. of dephlogisticated air. In this case, therefore, the dephlogisticated air that disappeared was 13.3 oz. m., weighing 7.8 grs., and the fixed air was 6 oz. m., weighing 44 grs. : so that here also about three times as much entered the blood as did not.

These experiments he repeated, and always with the same results ; the greater part of the dephlogisticated air, but never the whole, passing the membrane of the lungs, and entering the blood.

Dr. Priestley is of opinion that part of the phlogisticated air entered the blood as well as the dephlogisticated, the dephlogisticated air consumed not being of the purest kind. He thinks it very probable, that the deficiency of phlogisticated air was owing to the greater proportion of it in the lungs after the process than before.

When he breathed dephlogisticated air that was very pure, he generally found less loss of phlogisticated air, and in one case there appeared to be an increase of it ; but there will always be some uncertainty in the results of the long continued respiration of any kind of air, as the operation becomes laborious at last, and the quantity of air inspired and expired is therefore greater than at first. Being aware of this circumstance, he endeavoured to

obviate it's effects by leaving off with his lungs, as nearly as he could judge, in the same state of distension as when he began, which was always after a moderate expiration; so that two or 3 oz. measures would have made a very sensible difference, as will be found by actual trial.—Such are the ideas of this celebrated philosopher on the function of respiration.

The two great Swedish chemists appear to differ from *Bergman*, *Priestley*. *Bergman* and *Scheele* affirm, that the lungs, *Scheele*, or the blood they contain, absorb phlogiston from the atmospheric air, instead of rendering it, and they have supported this opinion by very ingenious experiments; so that, according to them, the atmospheric air, being deprived of it's phlogiston by the lungs, becomes incapable of entertaining life by serving respiration.

This ingenious Italian philosopher is of opinion, that *Fontana*; he has proved, from experiment, that not only phlogiston is separated from the lungs, but that fixed air is also disengaged from them; of which last fact he looks upon himself to be the discoverer. The office of respiration, according to *Fontana*, is that of depriving the blood of a superabundance of it's phlogiston. He thinks that the cause of suffocation in respired air arises from two causes; for, since the air is found to be composed of two parts, viz. fixed and phlogisticated airs, the fixed air acts upon the lungs and destroys life, because it is not only incapable of supporting life, but acts as a real poison, and may be called a positive cause; and the phlogistic air cannot entertain life, although innocent of itself, possessing no active power: but the animal dies in it merely through want of atmospheric air; and this may be called a negative cause. He thinks that one part of the fixed air expired by the lungs ought not to be attributed to the pulmonary phlogiston, as is generally believed, but that it is generated in the animal machine; whilst *Landriani*, in *Landriani*.

opposition, agrees with others, that it arises from the expired phlogiston uniting with the atmospheric air.

Lavoisier, from his experiments on different airs and on the air of the atmosphere, found that dephlogisticated air might be wholly converted into fixed air by the addition of powdered charcoal; and he read a paper to the Academy upon this subject in 1775: he thought therefore that respiration might be one process by which this is brought about; and having found that the atmosphere we breathe contains about one fourth part of vital air, and three fourths of azot gas, he suspected that the dephlogisticated air, when taken into the lungs, is thrown out again in the form of fixed air; and that the other part, which enters the lungs, and passes from them nearly in the same state, without any alteration, is merely passive.

Suspecting, therefore, the theory of his contemporaries, and finding it contradictory to a great number of phenomena, he proceeded on a different plan, and was, by the consequences of his experiments, led to form different conclusions.

Experiments of Lavoisier to determine the species of alteration the air undergoes from respiration.

In order to know the species of alteration which happens in the air after having been breathed by animals, he introduced a guinea-pig under a glass bell which contained 248 inches of oxygen gas. The glass was placed over mercury, and the animal left it in an hour and a quarter.

To render the comparison more easy, he supposes the quantity of oxygen gas to have been a cubic foot, or 1728 cubic inches, and calculates the results. When the animal was withdrawn from the glass, the number of inches was reduced to 1672½, which makes a diminution of 55½ inches: there were found at the same time 229½ inches of carbonic acid gas, as appeared by the introduction of caustic alkali; the rest was pure vital air.

By converting these volumes into weight, the quantities of air under the glass will amount to

	oz.	drac.	grs.
Vital air	1	2	$1\frac{3}{4}$
Carbonic acid gas	0	2	15
Total	1	4	$16\frac{3}{4}$

Hence the air in this experiment, although diminished by about $\frac{1}{32}$ of its volume, was increased in absolute weight; from which, according to this philosopher, it results,

1st. That air extracts something from the lungs during respiration.

2d. That the substance extracted, combining with vital air, forms carbonic acid gas; and since it is known that there is no other substance but carbon possessing this property, it follows, that by the process of respiration a real carbonaceous matter is extracted. But this increase of weight, which appears to be only 21.87 grs., is really much more considerable than at first appears credible; for in the above experiment only 229 $\frac{1}{2}$ inches of carbonic acid gas were formed. Now, after some very exact experiments, it has been found by Lavoisier that 100 parts of carbonic acid gas in weight are composed of 72 of vital air, and 28 of carbon: hence the 229.5 inches of carbonic acid gas obtained, contain

	grs.
Of vital air	11.484
Of carbon	4.466

The 11.484 grs. of vital air amount in cubic inches to 229 $\frac{1}{2}$: if, therefore, there was only sufficient vital air used to form the carbonic acid gas, the remaining quantity ought to be 1728—229 $\frac{1}{2}$.

	1498 $\frac{1}{2}$
There was found only	1443 $\frac{2}{3}$
Consequently a deficit of	54 $\frac{2}{3}$

Hence, according to Lavoisier, independently of the vital air converted into carbonic acid gas, a portion of that which entered into the lungs did not return in an elastic state; and therefore one of two things must have happened during respiration: a portion of the vital air either united with the blood, or combined with a portion of hydrogen gas to form water. Supposing the last, it is easy after the above experiment, says this chemist, to determine the quantity of water formed by respiration, and the quantity of hydrogen gas extracted from the lungs. For since, to form 100 parts of water, 85 parts of vital air in weight and 15 of hydrogen gas are employed, it follows, that with the 54 inches of vital air found wanting, 32.25 of water ought to be formed; and that there were 4½ grains of hydrogen gas disengaged from the lungs of the above-mentioned animal. From this and other

His conclusion.

Composition of the atmosphere.

experiments he was led to conclude that respiration only acts on the portion of oxygen gas contained in the atmosphere; that one portion is converted into carbonic acid gas, whilst the other is employed to form water. According to Lavoisier, the atmosphere is composed of 0.27 of pure air and 0.73 of azot; but it had long been suspected by de la Metherie that fixed air likewise made a part of it, and Humboldt has since proved he was right in his conjecture. He found that in its ordinary quantity it amounts to 0.014, that its maximum is 0.018, and its minimum 0.005; and this quantity is so strongly allied to the azot and oxygen as not to be separated by the greatest portion of water the atmosphere contains. According to this chemist, it appears likewise, that it is not the quantity alone of oxygen contained in the atmosphere that renders it proper for respiration, as in mines he found air which extinguished light and killed animals, that contained even 0.27 of oxygen.

Hence he affirms it is not the default of oxygen that

renders noxious atmospheres or mofets fo mortal, but the manner in which this oxygen is combined. The atmosphere therefore is not a fimple mixture of 0.97 of oxygen, 0.72 of azot, and 0.01 of carbonic acid, but there is a real combination of all thefe principles united to the aqueous portion: he found that the oxygen the atmosphere contains varied from 0.23 to 0.29.

It appears there was no experiment of importance to determine the quantity of air the lungs contain, until that made by Borelli in the middle of the laft century. Having breathed through a glafs tube of which the volume was afcertained, and of which one end was immerfed in fome bubbles of foap, he found the quantity of air received into the lungs in one infpiration to be about 15 cubic inches; and towards the end of the experiment to be between 18 and 20 cubic inches. This experiment however is liable to objection; for it is, according to Menzies, not only inaccurate, from the friction and other caufes, but it is only the meafure of one infpiration.

The next author is the celebrated Jurin. He fufpended a weight to the lower part of a bladder, previoufly moiſtened; and having fixed a tube of about an inch diameter in the upper part, he ſtopped his noſtrils and inſpired the air of the bladder gently, during three minutes, the weight remaining all the while on the table. He then plunged the bladder, with the air encloded in it, and the weight fufpended to it, into water contained in a cylindrical veſſel: he then marked the height to which the water roſe. Having now ſqueezed the air out of the bladder, he again plunged it into the water with the weight. The difference of the height to which the water roſe in both theſe caſes was eaſily calculated. Having repeated the experiment ten times, and added the quantities together, the tenth part of the ſum total, or the proportional difference of the height to which the water roſe

Experiments to determine the quantity of air the lungs contain.

Jurin.

in both cases, was found equal to 35 cubic inches, which is the volume of air contained in the bladder; and having added about the twelfth part, or three inches, on account of the condensation of the air from the coldness of the water, as it was winter, it amounted to 38 cubic inches. He added a little, both on account of the pressure of the water on the bladder, and of the moisture which is expelled with the air, and soon condensed by the coldness of the water and of the bladder. He then calculated the quantity of air, expelled by a moderate expiration in the space of three minutes, at 40 cubic inches. In the strongest expiration he expelled 125 cubic inches in the space of a minute; but in a strong expiration, continued nearly until suffocation, he expelled 220 cubic inches from the lungs. Hence it follows that there is more air in the lungs than can be expelled by an ordinary expiration.

This experiment proves that the quantity of air usually expired is equal to 40 cubic inches. The accurate Hales, Haller, and Sauvages, who have repeated these experiments, have agreed that the result was the same. But according to Menzies, as it is only the measure of one inspiration, it lies open to the same objection as the former.

Dr. Goodwin.

This was also attempted by Dr. Goodwin. He endeavoured to breathe from a vessel full of air, joined by means of a tube to another full of water, so that a certain volume of water, equal to that of the air inspired, might get into the place of the latter after each respiration; for the volume of water, substituted to that of the air inspired, must be equal to that of the air consumed in inspiring.

Having contrived an apparatus for this purpose, an adult of a middle size, and in good health, endeavoured to respire as naturally as possible from this pneumatic vessel, and the

First time, he inspired 3 cubic inches;
Second time, 2½

Another person of the same stature endeavoured to breathe out of the vessel.

At the first inspiration, he breathed $3\frac{1}{2}$ cubic inches;

At the second, $2\frac{3}{4}$.

But as the difference of the result of both these experiments might be supposed to proceed from the different degree of attention, he varied the experiment in this manner. The same man inspired and expired thirty times out of the same vessel, and as nearly as possible with the same degree of exertion; and on calculation the average quantity of air of each respiration was found to be $2\frac{3}{4}$ cubic inches.

Having repeated the same experiment with the greatest care, the average quantity of each respiration was found to be 3 cubic inches.

Another man of the same stature breathed 30 times from the same vessel, and in the same manner, and the average was $3\frac{1}{4}$ cubic inches. Hence it follows that the greatest quantity of air received into the lungs during each natural respiration does not exceed $3\frac{1}{2}$ cubic inches; which is much less than what Hales and Jurin had calculated.

In the last dissertation of Dr. Goodwin, it appears that a dull kind of pain was felt in the chest before the man had finished the number of inspirations. Having removed the tube from his mouth, it was necessary to make a deep inspiration; which appears to Menzies to prove, that the quantity of air received into the lungs was not sufficient for the purposes of respiration. This defect however is attributed by the author to the imitation of natural respiration, which could not counterbalance the difficulty of raising water contrary to its natural gravity. As an attempt to breathe in the open air would not give the measure of an ordinary inspiration from the machine, it was necessary to assist the action of the lungs,

by which the quantity received was much increased ; as is evident from the following experiment, in which three persons of ordinary stature inspired from the machine 30 times successively, and took in as much air at each time as the sensations in the breast seemed to require. The average quantity of air taken into the lungs at a single inspiration

By the first, was 12 cubic inches.

second, . . 14

third, . . 11

Thus Dr. Goodwin concludes the quantity of air inspired to be equal to 12 cubic inches, which are dilated by heat to 14 ; and as the quantity of air remaining in the lungs, after an ordinary expiration, is near 109 cubic inches, he concludes, the proportion of the dilatation of the lungs, before and after a healthy inspiration, to be as 109 to 123.

Menzies.

Dr. Menzies, who is the last that has made any experiments of this nature, although he is of opinion that Dr. Goodwin has come very near the point, yet in the different experiments on the subject he found no confidence could be placed in the method he employed, on account of the inaccuracies it was liable to ; and he freely confesses it was by chance he first discovered them. The method which Dr. Menzies used seems to be similar to that indicated by Boerhaave.

It consists in being placed up to the neck in water, and judging of the dilation of the lungs from the ascent and descent of the water. Dr. Menzies therefore procured a hogthead, the top of which had an opening sufficiently large for the head to pass out ; and a cylinder was fitted about his neck up to the chin, by which the rising and falling of the water during respiration might be calculated.

1st Experiment.

A healthy man, five feet eight inches high, was shut

up in this hogthead, which was filled with water heated to 90° of Fahrenheit, as far as that part of the neck that was best suited to measure the difference of ascent and descent. This difference was about 1.25 inches. His pulse before and after immersion beat 64 or 65, and his respirations were 14 or $14\frac{1}{2}$ in a minute, and they continued the same all the time he remained, which was two hours and upwards, during which the ascent and descent of the water were $1\frac{25}{100}$ inch at least: but when he made a deep inspiration, so much air rushed into the lungs that the water passed out through the cylinder; but as the area of the cylinder was 55.41 square inches, and the area of the neck 18; $55.41 - 18 \times 1.25 = 46.76$ cubic inches, the quantity of air usually respired by this man. This was thrice repeated with the same result; but to prevent mistake he was made to breathe through an allantoid.

This allantoid contained 2700 cubic inches, which in many trials he filled with 58 expirations, giving 46.55 cubic inches as the quantity of air expired; and this calculation is very near the preceding one. But as the respirations of this man appeared to be never more than 14 and $14\frac{1}{2}$ in a minute, it was probable he inspired more air than other men of the same stature. To ascertain this, and to be able to estimate the average quantity of air inspired, it was necessary to examine the respiration of a man of small stature.

Another man, therefore, only five feet and an inch ^{2d Experiment.} high, was shut in the same hogthead; the pulse beat 72, and the number of respirations was 18 in a minute. The water was heated between the 85th and the 90th of Fahrenheit. The difference between the ascent and descent during the long time he remained was 0.95 of an inch, or in vulgar fractions $\frac{95}{100}$ of an inch. The area of the cylinder was equal to 57.012 inches, and the area of the

neck to 14.0837 inches. Hence $57.012 - 14.0837 \times 0.95 = 40.781$ cubic inches, is the quantity of air taken into the lungs by a common respiration. This was confirmed by his breathing into the allantoid, which gave from 38 to 40 cubic inches, the measure of a common inspiration. So that, if half the quantities of the two experiments be taken, there will be 43.77 cubic inches, the average quantity of air respired. The ascent and descent of the water were carefully marked by means of a glass tube inserted into the top of the hoghead, on which a scale of degrees was cut; and on account of the attraction between the water and the sides of the tube $\frac{1}{8}$ was subtracted; and if on account of the dilatation of the air by the heat of the lungs $\frac{1}{472}$, for every degree of heat be subtracted, the quantity of air inspired may still be computed at 40 cubic inches.

Dr. Goodwin supposes that only 109 cubic inches remain in the lungs after an ordinary expiration, and that the proportion of their dilation after an ordinary expiration is to that of their dilatation after an ordinary inspiration as 109 to 123; but Dr. Menzies has remarked, that after an ordinary expiration a man could still expel 70 cubic inches of air from the lungs. Hence after such an expiration only 39 cubic inches of air will remain. "Without doubt then," says Dr. Menzies, "as appears from another experiment (Goodwin's Connexion of Life with Inspiration, p. 46), Dr. Goodwin supposes that 109 cubic inches of air remain in the lungs after an extraordinary expiration: but as we have found 70 cubic inches to be the difference between an ordinary and an extraordinary expiration, this number added to the former, or to 109, will give 179, as the quantity of air remaining in the lungs after an ordinary expiration. Now the former experiments show, that the quantity of air expelled by an ordinary

“ expiration is equal to 40 cubic inches : consequently,
 “ if this be added to 179, we shall have 219 cubic inches
 “ as the quantity of air contained in the lungs before
 “ expiration : hence the dilatation of the lungs before and
 “ after an ordinary expiration will be as 219 to 179 : or,
 “ in other words, the thorax will be increased by a
 “ quantity of air nearly equal to a cube of $3\frac{1}{2}$ inches ;
 “ which, if we consider how much the thorax and abdo-
 “ men are dilated by an extraordinary inspiration, seems
 “ very trifling. The difference between an extraordinary
 “ expiration, or one made with some effort, and an extra-
 “ ordinary inspiration, I have found to exceed 200 cubic
 “ inches.”

As the atmospheric air undergoes a change by respira-
 tion in the proportion of it's constituent parts, the de-
 phlogisticated air being diminished, the fixed air increased,
 whilst the phlogisticated remains the same ; Dr. Goodwin
 was desirous of ascertaining the particular degree of these
 changes : he therefore began by finding the proportion
 of the airs in 12 cubic inches of atmospheric air ; which
 being done, he inspired an equal volume of the same air,
 and then expired it into a glass receiver, and analysed the
 whole quantity. This having been repeated several
 times, the medium was as follows :

Dr. Goodwin's experiments to ascertain the degrees of change the parts of the atmosphere undergo in respiration.

Parts.				Parts.			
The volume of air taken into the lungs at a single inspiration contained of phlogisticated air				The volume of air expelled from the lungs by the next succeeding expiration contained of phlogisticated air			
-	-	-	80	-	-	-	80
Dephlogisticated air			18	Dephlogisticated air			5
Fixed air			2	Fixed air			13
<hr/>				<hr/>			
100				98			

He found this diminution of the dephlogisticated air was sometimes $\frac{1}{30}$ th or $\frac{1}{40}$ th part.

He then attempted to find if this diminution of the one and increase of the other be constant and uniform in the same volume of air several times respired; for which purpose, he first examined the diminution of the dephlogistified air, by breathing a quantity of air several times from a glass receiver inverted in water; and by mixing a small quantity of this same air, after every expiration, with an equal quantity of nitrous air in Fontána's eudiometer, in which the quantity of dephlogistified air would be indicated by the diminution of volume in the eudiometer: he therefore passed 12 cubic inches of atmospheric air into a glass receiver inverted in water, and put a measure of it into this instrument, where it occupied 100 parts: he then added an equal measure of nitrous air, and the whole volume of 200 parts was diminished to

to	-	-	-	-	-	-	-	-	-	144
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Then he inspired the whole of the volume from the receiver, and expired it in the usual time; and on trying an equal portion of it in the instrument, the 200 parts were diminished to	-	-	158
After the second expiration, to	-	-	163
After the third, to	-	-	167
After the fourth, to	-	-	170
After the fifth, to	-	-	171

2dly. To determine whether the addition or increase of the fixed air be uniform and constant in several successive respirations, he enclosed 12 cubic inches of air in an inverted receiver, and breathed it through a glass tube six times in succession; when, on being examined with lime water after the last expiration, it contained 15 parts of fixed air: on repeating the experiment, the quantity of fixed air was 13 parts: hence the diminution of the dephlogistified and the increase of the fixed air is constant and successive in the same quantity of air frequently breathed; but the changes in the successive respirations

bear no proportion to the changes in the first. Dr. Goodwin, finding therefore these changes so constant and uniform, suspected they must be connected with some corresponding changes in the lungs, equally constant and uniform, which he found to be in the blood.

Count Morozzo, in order to prove the length of time different animals were able to live in different airs, so as to be able to form a comparison, made the following experiments :

The oxygen gas he used was extracted from red precipitate and nitre, which he found to be of equal purity : the animals were sparrows and rabbits, of an adult state, that he might be able to compare the results, having observed that animals lived a longer or a shorter space of time in a vitiated air according to their age ; which difference ceases on their arrival at maturity. He used the method employed by Dr. Cigna of exposing a succession of animals to the same gas, and found the results to be perfectly similar : he found that,

Experiments of Morozzo, on exposing animals to different species of air.

				Hours. Min.	
In atmospheric air, the 1st sparrow lived about				3	—
	2d	-	-	—	3
	3d	-	scarcely	—	1
In dephlogificated air, the 1st sparrow lived				5	23
	2d	-	-	2	10
	3d	-	-	1	30
	4th	-	-	1	10
	5th	-	-	—	30
	6th	-	-	—	47
	7th	-	-	—	27
	8th	-	-	—	30
	9th	-	-	—	24
	10th	-	-	—	21

On repeating his experiments in vessels of equal size, he found that animals lived four and even five times longer in dephlogificated than in common air ; that after

the death of the animal a lighted candle was immediately extinguished in the atmospherical air, but preserved it's brilliancy and vivacity in the dephlogisticated air, as if it had undergone no change; which is contrary to what Dr. Cigna observed, that common air when vitiated by respiration extinguishes flame a long time before animal life. He remarks with Dr. Priestley, that animals appear to be more gay and active in oxygen gas than in atmospherical air; and that, when their respiration appears troubled, they do not gasp for breath so much, nor is their death accompanied by such violent convulsions as in atmospheric air; and that the duration of their life in oxygen gas did not decrease in any marked proportion from the introduction of the fifth.

Having observed that oxygen gas, in which different animals have successively died, is still in a state of supporting animal life a considerable time, and flame with great vivacity, he was desirous of answering the following questions:

1. To find the duration of animal life in dephlogisticated air, in which a candle had been extinguished; and he found animals lived in it nearly as long as in pure oxygen gas.

2. To discover whether a lighted candle would burn in the oxygen gas in which flame had been extinguished, and he found it would not. In equal capacities, flame existed five minutes in oxygen gas, and only forty seconds in atmospheric air.

In order to discover the least variations, Morozzo used vessels of a larger capacity, containing forty pounds of water, and larger animals, such as rabbits; and he found that,

	H.M.	Inch. Lin.
In atmospheric air, the 1st lived	4 33, and the absorption	0 9
2d	- 0 13, - - - -	0 4
3d	- 0 5 - - - -	0

			H. M.			Inch. Lin.
In oxygen gas	-	1ft	-	10	3,	2 0
		2d	-	3	57,	1 8
		3d	-	4	30,	2 2

He remarked with Dr. Priestley, that quadrupeds live longer than birds in vitiated air, from being accustomed to breathe nearer the ground, where the air is not so pure as in the higher regions; and he lays it down as a rule, that animals in oxygen gas consume a quantity in proportion to common air as 5 to 1; which is the same proportion as that of the greatest durability of their lives.

From exposure of animals in different airs, he found,

1. That the duration of animal life was in proportion to the greater quantity of oxygen gas the airs contained. Conclusions.

2. That in all where there was an equal part of oxygen gas, they lived considerably longer than in common air, except in the air vitiated by the vapour of charcoal, in which a sparrow lived only 24 minutes, and in fixed air 38 minutes.

3. That in all those of which one-third was oxygen gas, animal life was nearly equal to what it was in common air, except in the two last cases.

4. Gases and infectious airs appear to be fatal in the order following:

Inflammable gas of marshes	-	-	-	} nearly equal.
Air vitiated by vapour of sulphur	-	-	-	
-----by burning charcoal	-	-	-	} nearly equal.
-----by a mixture of iron filings	-	-	-	
and moistened sulphur	-	-	-	
Inflammable gas from iron and vitriolic acid	-	-	-	
Fixed air	-	-	-	} nearly equal.
Air vitiated by animal respiration	-	-	-	

Dr. Priestley has likewise made some experiments on animals in noxious airs; from which he found that animals, on being put into air in which other animals have died, Priestley's experiments on animals in noxious airs.

almost always die in convulsions: they are sometimes affected so suddenly as to be irrecoverable after a single inspiration, although withdrawn immediately, and every care taken to recover them. They are affected in the same way in every other noxious air; such as fixed air, inflammable air, air filled with fumes of sulphur, infected with putrid matter, in which a mixture of iron filings and sulphur has stood, or in which charcoal has been burned, or metals calcined, or in nitrous air. According to Dr. Priestley, animals become habituated by degrees to the noxious air; for he frequently found, that when a number of mice had been confined in a given quantity of air, a fresh mouse being introduced to them has been instantly thrown into convulsions, and died. It is evident, therefore, that if the experiment of the black hole at Calcutta were to be repeated, a man would stand the better chance of surviving it who should enter at the first than at the last hour. Dr. Priestley has also observed, that young mice will live much longer than old ones, or than those which are full grown, when they are confined in the same quantity of air. He has known a young mouse to live six hours in the same circumstances in which an old mouse has not lived one: hence the uncertainty in making experiments of this kind, where a frequent repetition is necessary to depend upon them.

Having given some account of the ancient and modern opinions of respiration in general, of the experiments that have been made on the effects of respiration upon air, of the changes it suffers from this process, of the formation of new substances found in expired air, of their proportions, of the opinions of several chemical physiologists upon the quantity of air the lungs contain, and of the experiments made upon animals in different species of airs, the next part of the subject relates to the colour the blood receives during the respiratory process, beginning with

some account of the opinions of different philosophers upon this subject.

Colour of the Blood.—The ancients must undoubtedly have observed, that the surface of blood, after having been drawn from the body and left to repose, changed from a dark to a florid red colour, and that underneath it remained black; but they could have had no just idea of the cause of this change. It appears, that, among the moderns, Mayow was the first whose conjectures were conformable to the latest experiments. He says, that the fluid red colour of the blood is produced by the introduction of the nitroaerial spirit from the atmosphere; for where the blood is not exposed to this, it is black. As, however, this celebrated author's publication was scarcely known to exist previous to its being introduced to public notice by Dr. Beddoes, nobody, unless we accept Lower, attempted to account for this difference, or the cause of the colour. Even so late as the time of Haller all was conjecture: this celebrated physiologist, on comparing the blood of an adult with that of the foetus, which is destitute of the florid redness, only informs us that it was acquired in the lungs. The common opinion was, that the change of blood, on standing, arose from its containing two kinds of particles, red and black; and that the black, from their greater specific gravity, fell to the bottom, whilst the red particles remained at the surface.

Cigna of Turin, at length, having paid great attention to this subject, published a memoir in the first volume of the *Miscellanea Taurinensia*, in which he very well accounts for this red colour of the blood, clearly proving it to be caused by the contact of air. He found, that, on covering the blood with a little oil so as to defend it from the atmosphere, it remained black throughout; but when he took away the red part, and exposed the lower *laminæ* to the air, which were black, they also became

ſucceſſively red, till the whole maſs had acquired this colour. At the requeſt of Cigna, father Beccaria was induced to try the effect of expoſing blood in the vacuum cauſed by an air-pump, and he found that it always remained black, but became red on expoſing it again to the atmioſphere. Cigna concludes by obſerving, that it is not eaſy to account for the lower part of a maſs of blood becoming black, whether it ariſes from the air it has imbibed eſcaping from it, or from it's depoſiting ſomething ſaline, neceſſary to contribute to it's redneſs, or from the preſſure of the atmioſphere; but he ſeems to think, that air mixed with blood, and interpoſed between the globules, preſerves it's redneſs; but that by concreting it is expelled from it, or becomes ſo fixed as to be incapable of making it red. This opinion, he imagines, is rendered in ſome meaſure probable, by the increaſed density of concreted blood, and by the emission of air from other fluids in a concreſcent ſtate. In another memoir, he doubts whether the change of colour in the blood takes place in the lungs, but if it does, he is inclined to aſcribe it to the *evaporation* from the blood in the lungs; and though he always found the colour of the blood was changed by the contact of air, yet when he conſidered that evaporation muſt neceſſarily attend the contact of air, he ſuppoſed that this effect might equally be attributed to it. But he acknowledges confirmation by experiments is neceſſary to this hypotheſis.

Hewſon.

Other experiments were made by Hewſon. He found that a ſolution of nitre changed dark-coloured blood to the moſt beautiful red; but is of opinion that this cannot ariſe in the lungs, ſince the air contains no nitre; and he found moſt of the neutral ſalts in ſome meaſure produced the ſame effect. He was certain, however, that, as the colour of the blood is changed by air out of the body, the air is the immediate cauſe of the ſame change in the body; and this change in the venous and arterial blood is pro-

duced in the lungs, he affirms, from experiments in which he distinctly saw the blood of a more florid red in the left auricle of the heart than in the right; but how the effect is produced he thinks is undetermined.

The cause of this change was determined by Dr. Priestley; but he attempts to explain it according to the phlogistic system. He endeavoured to find whether blood was of such a nature as to retain the power of phlogisticating air when congealed, and out of the body, that it has when fluid and in the body; and the experiment answered his expectation. Having taken the blood of a sheep, and let it stand till it was coagulated, and the serum separated from it, he introduced pieces of the crassamentum, contained in nets of open gauze or of wire, sometimes through water, and sometimes through quicksilver, into different kinds of air, and always found that the blackest parts assumed a florid red colour in common air, and more particularly in dephlogisticated air, and in less time; whereas the brightest red blood became presently black in any kind of air unfit for respiration, such as fixed, inflammable, nitrous, or phlogisticated airs; and after becoming black in the last of these kinds of airs, it regained it's red colour on being again exposed to common or dephlogisticated airs; the same pieces becoming alternately black and red by being transferred from phlogisticated to dephlogisticated air, and *vice versa*.

In these experiments, Dr. Priestley is of opinion, that the blood loses it's black colour by giving it's phlogiston, which is the cause of it, to the air; and that it receives it again on being exposed to the other airs containing this principle. He thinks that the blackness of the blood may arise from other causes than it's acquiring phlogiston, as in vacuo; and such he found to be the case when it was covered two inches and a half with serum, but regained it's florid colour again on exposure to the open air. He exposed

pieces of the same mass to nitrous and inflammable as well as fixed airs; they all became black, but that in the inflammable the least so; but none of them recovered their fluid colour in the open air; one, however, in fixed air, recovered it in dephlogisticated air. The deeper the colour, the more the phlogiston it contains, and *vice versa*. As it might be objected to this hypothesis of Dr. Priestley, that the blood never comes into actual contact with the air in the lungs, but is separated from it; and that the red globules also swim in a large quantity of serum, a fluid of a quite different nature; in order to ascertain the effect of these circumstances, he took a large quantity of black blood, and put it into a bladder moistened with a little serum, and, tying it very close, hung it in a free exposure to the air, though in a quiescent state; and the next day he found that all the lower surface of the blood separated from the common air by the bladder (which is an animal membrane like the vesicles of the lungs, and at least as thick), and likewise a little serum, had acquired a coating of a florid red colour, and as thick as if it had been immediately exposed to the open air; so that the membrane had been no impediment to the action of the air on the blood. He repeated the experiment without previously moistening the bladder, and with the same result. He found that a piece of the crassamentum acquired the florid colour even when covered with serum to the depth of several inches; but, that the slightest covering of water or saliva effectually prevented it's acquiring this colour, which proves how wonderfully well the serum is adapted as a vehicle for the red globules. To satisfy himself completely that it is really the air acting through the serum, and not the serum itself that gives the florid colour, he took two equal portions of black blood, and put them into equal cups, containing equal quantities of serum, which covered them to the depth of half an inch. One of these

cups he exposed to the air, and the other under an exhausted receiver, when the former presently acquired a florid colour, and the other continued twelve hours as black as the first. It also remained black when exposed to the air, and the serum taken off. He reversed this experiment, and found that red blood became black through the depth of two inches of serum, exposed to phlogisticated air; a confirmation that the red globules of the blood receive and part with phlogiston by means of the air, notwithstanding the interposition of a large body of the fluid in which they naturally float.

Dr. Priestley, however, does not infer, in all cases, that blood becomes black by imbibing phlogiston *ab extra*; for, if time be given it, this change may arise from *internal causes*, as from putrefaction, which he found by experience.

Except serum, he found that milk is the only animal fluid through which the air can act upon blood, for black blood became red when plunged into milk as if covered with serum. It becomes instantly red in urine, which he attributes to the saline nature of that fluid. This makes it probable, that the redness of the blood is owing not only to its *parting* with phlogiston, but to *imbibing* the acidifying principle from the dephlogisticated air.

As the principal use of the blood appears to Dr. Priestley to be derived from its power of receiving and discharging phlogiston, and the degree in which it possesses this power is easily ascertained by the eye, it might, he thinks, be worthy the attention of physicians; for in cases in which the blood is unusually black, and but little affected by common air; perhaps breathing a purer air might be prescribed with advantage. In general, the blood he procured in the city was not so good as that got in the country, which he attributes to the cattle having been much driven and heated before they were killed.

It appears from Dr. Priestley's account, that having afterwards made some experiments on the mutual transmission of dephlogisticated air, and of inflammable and nitrous, through a moist bladder interposed between them, and from the opinions of others, he was soon convinced, that, besides the emission of phlogiston from the blood, dephlogisticated air, or the acidifying principle of it, is at the same time received into the blood; yet he appears still to be of opinion, that although the application of dephlogisticated air to the outside of a vein may change the colour in it, as Dr. Goodwyn has proved, this might have been affected, as he first supposed, by the simple discharge of phlogiston from the blood, when it had an opportunity of uniting with the dephlogisticated air thus presented to it.

Lavoisier
and
Crawford.

Lavoisier and Crawford formed their opinion of the colour of the blood from the experiments which Priestley and Hamilton made. The last made three ligatures upon the jugular vein of a cat; having extracted the blood comprehended between two of these ligatures, he introduced hydrogen gas into it, and detained it by closing the orifice; he then united the middle ligature, and the blood between the third ligature and that of the middle became in contact with the hydrogen gas. Having drawn the blood from the vein, he found it liquid, and that it had acquired a colour nearly as deep as ink. Venous blood exposed to vital air acquires the vermilion colour of arterial blood, and the vital air is vitiated. From these experiments, Lavoisier and Crawford are of opinion, that the change of colour the blood undergoes in the course of circulation proceeds from it's uniting with hydrogen; that the blood when it passes through the lungs communicates a part of it's hydrogen to the oxygen contained in the inspired air, and that it then receives it's red colour again.

Dr. Good-
wyn.

It had long been observed by Löwer (Tract. de Corde, p. 185.), in living animals, that the blood from a wound

in the trunk of the pulmonary vein was florid; and knowing before that the blood entering the lungs by the pulmonary artery is black, he concluded that it acquired this florid colour by passing through the lungs; and finding afterwards, that when the animal ceased to breathe, the blood from the wound in the pulmonary vein was black, he attributed the florid colour to the action of the air in respiration. Dr. Goodwyn, struck with this fact, undertook to examine the truth of it. He procured some large dogs, removed the sternum, and exposed the trunks of the pulmonary veins and arteries, so as to be able to distinguish accurately the colour of the blood passing through them. He then inflated the lungs with bellows, as described by Vesalius, so as to imitate the natural respiration, and he kept the animal alive by this process a considerable time. In these experiments he observed, that, during the inflation, the blood in the trunks of the pulmonary artery was black, but in the trunks of the pulmonary veins florid; and when the inflation was intermitted for a minute, the blood in the trunks of the pulmonary vein became gradually black, like that in the arteries. Dr. Goodwyn likewise confirmed Lower's opinion by other experiments on the toad and lizard, whose lungs consist of only a transparent bladder, with blood-vessels so thin that the colour of the circulating blood may be easily distinguished through them; and in all the examples, when the air passed into the lungs; the blood in the pulmonary vessels became gradually florid; but when they were emptied by pressure, it became gradually black.

Dr. Goodwyn then inquired to what part of the air respired this change of colour was owing, whether to the addition of fixed air separated from the blood in passing through the lungs, or to the action of the phlogisticated or dephlogisticated air. He found by experiment, that

fresh drawn florid blood exposed to fixed air underwent no sensible change, and as black blood fresh drawn undergoes no change of colour when exposed to dephlogisticated air, he tried what the change of venous black blood would be when exposed to dephlogisticated air, and found, in support of the common assertion, that it became florid, whilst a small portion of the air disappeared during the process; hence he is disposed to believe, that when the dephlogisticated air produces this change, something at present unknown pervades the coats of the pulmonary vessels by the force of chemical attraction.

Dr. Goodwyn concludes that,

1. A quantity of dephlogisticated air is separated from the atmospheric air in the lungs.

2. That this dephlogisticated air exerts a chemical action upon the pulmonary blood, in consequence of which it acquires a florid colour.

Girtanner.

If arterial blood be exposed to hydrogen gas in a glass vessel, the quantity of gas is diminished, and the vermilion colour of the blood is changed to a deep colour. In this experiment, according to Girtanner, the contrary passes to what it does in respiration. The hydrogen gas in the last case unites to the oxygen of the arterial blood, to form water, and the arterial blood being deprived of oxygen becomes black, and is changed into venous blood, its deep colour arising from the loss of its oxygen. The experiment of Hamilton, before quoted, is explained by Girtanner in the same way. In this case the blood was found liquid, and little coagulable, which Girtanner likewise reckons in his favour; for in his first memoir he asserted, that the coagulability of the liquids followed the same laws, and depended upon the same principle, as the irritability of the solids, consequently the blood deprived of the irritable principle, or of the oxygen, ought to be liquid, *i. e.* little or not coagulable. This chemical physiologist,

after having shown that the arguments hitherto brought are not convincing, proceeds to bring proofs in favour of his own theory.

1. *Venous Blood.* Six ounces of black venous blood, drawn from the jugular vein of a sheep, were exposed to oxygen gas under a glass. It was instantly changed to a vermilion colour; the thermometer mounted a few degrees, and descended again. The mercury under the glass arose six or eight lines. The blood weighed a little more than before. This proves, according to Girtanner, that the blood during respiration absorbs oxygen. This was confirmed by a second experiment. He opened the jugular vein of a sheep, and received the blood in a bottle filled with oxygen gas, and the bottle when half full was stopped. The blood immediately became of a vermilion colour, very fluid, and only coagulated slowly into a thick and reddish mass, from which no serum was separated.

He injected a pretty considerable quantity of very pure oxygen gas into the jugular vein of a dog, which killed it in less than three minutes. He found the heart more irritable than ordinary. The right auricle and ventricle contained blood of a vermilion colour not coagulated. The blood in the left ventricle, the aorta, and the arteries, was of a rose-colour, and mixed with blebs of air. This proves that the vermilion colour is not owing to the loss of carbonated hydrogenous gas in respiration, but to the blood combining with the oxygen gas. In this experiment, the deep colour of the venous blood of the right auricle and ventricle was changed into a vermilion; yet there could be no loss of carbonated hydrogenous gas; there was only an addition of oxygen gas.

He injected a small quantity of azot gas, deprived of fixed air by lime-water, into the jugular vein of a dog, which died in twenty seconds. The blood of the right auricle and ventricle was black, thick, and coagulated.

The left ventricle was of it's ordinary colour. He found that the venous blood of a sheep exposed to azot became black nearly as ink, and coagulated immediately ; that a quantity of serum was separated, and the following day a slight odour of ammonia was perceived on opening the bottle.

This proves that the colour of the blood arises from the azot ; and the ammonia from the union of the same azot with the hydrogen gas of the venous blood. The colour of the blood becoming more deep after having lost a part of it's hydrogen, appears to prove that this deep colour is owing to the carbon of the blood, and not to the combination of the hydrogen gas, as is thought. The venous blood of a sheep exposed to carbonic acid gas in a bottle immediately coagulated, became of a very deep colour, and a great quantity of reddish serum separated. A small quantity of carbonic acid gas being injected into the jugular vein of a dog, killed it in a quarter of an hour. The blood of the right auricle and ventricle was thick, and in part coagulated ; that of the left was of a much deeper colour than usual. This likewise proves that the deep colour of the venous blood is not owing to the combination of hydrogen gas. One part of the oxygen of the carbonic acid gas probably united to the hydrogen of the blood to form water, and the carbon previously united to this oxygen combined with the blood, and gave it a deeper colour.

The venous blood of a sheep being exposed to nitrous gas, immediately coagulated, and a great deal of blackish serum separated. The next day, on opening the bottle, a very strong odour of nitric æther (dulcified spirit of nitre) was perceived, the nitrous gas having been in part changed into nitric æther by the carbonated hydrogen of the venous blood ; which proves that the venous blood contains carbonated hydrogenous gas, which is easily se-

parated. The blood having lost this gas, had not received it's vermilion colour; but, on the contrary, a deeper colour. The deep colour of the venous blood is not, therefore, owing to it's union with carbonated hydrogen, since it becomes deeper after the separation of the hydrogen.

A small quantity of nitrous gas injected into the jugular vein of a dog, killed it in less than six minutes. The blood in the right auricle and ventricle was black, thick, and in part coagulated: that in the left was much more deep than usual.

2. *Arterial blood*.—Some arterial blood, from the carotid artery of a sheep, was exposed to oxygen gas in the same way as the former experiments were made; and it immediately received a more vermilion colour. The day after, a very small quantity of carbonic acid gas was found mixed with the oxygen gas.

Arterial blood immediately coagulated with azot gas, and became of a very deep colour. The day after, a small quantity of oxygen gas was found mixed with the azot gas, so that a candle burned in it nearly two minutes. This experiment proves, 1. that arterial blood contains oxygen gas: 2. that it's vermilion colour is owing to it's union with this gas; and that, as soon as it is deprived of it, it assumes it's deep colour again.

The blood exposed to carbonic acid gas received no effect from it, although it has a great effect on venous blood. Exposed to nitrous gas, it immediately coagulated; and it's surface was green, and a little greenish serum separated. The day after, vapours of nitrous acid were observed on opening the bottle. This likewise proves the presence of oxygen in the blood, by it's converting the nitrous gas into nitrous acid; the green was owing to a small portion of azot, which separated from the nitrous acid. Exposed to hydrogen gas, it became

more vermilion-coloured, and remained fluid some time before it coagulated, when a little serum separated. The next day a little oxygen gas was found with the hydrogen gas; this also, according to Girtanner, proves the presence of oxygen gas in the arterial blood.

A small glass tube filled with arterial blood, and sealed hermetically, was exposed to the light; it's colour changed by degrees; and, in six days, it was as black as venous blood. This repeated, but exposed to heat instead of light, the blood became black in a much less time. These two last experiments, first made by Dr. Priestley, appear to Girtanner to prove it is not to the contact of hydrogen gas that venous blood owes it's black colour. From these experiments Girtanner concludes that,

1. The change of colour in the blood, during circulation, is not owing to it's combination with hydrogen gas.
2. That the vermilion colour of arterial blood arises from oxygen, with which the blood combines during it's passage through the lungs.
3. That the deep colour of the venous blood is owing to the carbon it contains.

Haffenfratz. Haffenfratz agrees pretty much with Girtanner. His opinion is, that the red colour of the blood proceeds from the solution of oxygen gas, and that it's brown and even black colour is occasioned by union of the hydrogen and carbon with the oxygen it holds in solution. He draws his conclusion from these facts. He first states the two facts upon which all chemists are of accord—1. that venous blood, mixed with oxygen, immediately receives a beautiful vermilion colour; that this red colour changes, by degrees, and becomes of a purple, like the ley of red wine, although the blood has been continually in contact with the oxygen, and both air and blood be constantly shaken together in order to unite them. 2. That arterial

blood, exposed to the action of every gas which does not contain oxygen, receives a colour of the ley of wine. From these he infers, that the red colour proceeds from the solution of oxygen in the blood, and it's purple colour from the oxygen abandoning the blood, and uniting with it's hydrogen and carbon. The experiments Hassenfratz made to convince himself of this are, he found that oxygenated muriatic acid, when added to venous blood, immediately decomposed it, and gave it a deep and almost black colour. He poured the same quantity of common muriatic acid into the quantity of blood, and the blood was immediately decomposed, and flocks of a clear brown were precipitated, that had not the black colour it took with the oxygenated muriatic acid. Since the difference between the oxygen of the oxygenated muriatic acid and oxygen gas is, that the first is in a state so as immediately to combine on being put into contact with the hydrogen and carbon of the blood, whilst the second is in a state which renders the combination difficult, it follows, that the colour the blood suddenly takes with the oxygenated muriatic acid, is that which blood ought to take, in length of time, with oxygenous gas. Thus the black colour of the blood is the result of the intimate combination of the oxygenous gas with the carbon and hydrogen of the blood, whilst it's red colour is only the result of the solution of oxygen gas in the blood. To assure himself more positively of this truth, he repeated an experiment of Girtanner: he filled several glass tubes full of blood made red by oxygen gas, and sealed them hermetically; some of which he put into the light, others into the dark, and he found that the blood in all was become blackish, like the ley of wine. The reason therefore of the two phenomena which have excited the curiosity of all philosophers, viz. the red colour of the blood in contact with oxygen, and the brown colour when in contact

with the other gases, are easily explained. As long as the blood is in contact with oxygen, and this gas is dissolved in the blood, it is of a beautiful red ; but when it is in contact with gases that contain no oxygen, that which is dissolved in the blood, and which occasions it's vermilion colour, quits, by degrees, the whole mass of blood to combine partially with it's hydrogen and carbon, and it's colour is brown ; and as the air in contact cannot furnish new oxygen, the colour continues to darken until all the dissolved oxygen is combined. This chemist likewise explains the particular fact observed by Fourcroy ; the diminution of the high red colour of the blood, constantly in contact with hydrogen gas, by the diminution of the force of attraction of the blood toward the oxygen gas, in proportion as it's carbon and hydrogen are combined with the gas of which it was first in possession ; which affords a belief, that, since the blood which circulates has always the same property of becoming red by mixing with oxygen, although it has already taken a considerable quantity, during it's circulation it takes from the substances with which it is in contact a quantity of hydrogen and carbon, equal to that which successively combines with the oxygen. He then made some observations on the hypothesis of de la Grange. He observes, that since the red colour of the blood is the consequence of the solution of oxygen gas in it ; since the purple colour of the ley of wine, and even the dark brown colour, proceed from the union of oxygen gas with the carbon and hydrogen of the blood ; since the venous blood is purple, and the arterial blood vermilion ; it follows, that the arterial blood contains oxygen gas in solution, that this oxygen unites itself by degrees with the hydrogen and carbon of the blood during it's circulation, and when the blood returns by the veins into the lungs all the combination is made, and that it there dissolves again

oxygen gas, to return with a vermilion colour into the arteries. As the dark brown colour of the blood is in consequence of the union of oxygen with the carbon and hydrogen of the blood, and as the blood on passing from the veins into the lungs to return back into the arteries becomes vermilion, it follows, that in the lungs very little union takes place between the carbon and hydrogen of the blood with the oxygen of the inspired air, and that the greatest combination is made during the circulation. It follows, therefore, on concluding, according to Hassenfratz, that,

1st. The red colour of the blood is the result of it's dissolving oxygen gas.

2d. That it's brown and even black colour arise from the combination of the hydrogen and carbon of the blood with the oxygen dissolved in it.

According to Davy, the arterial blood owes it's fine ^{Davy.} vermilion colour to light and oxygen, or the phosoxxygen entering into it's composition; and the venous blood is black, from a deficiency of phosoxxygen, and a superabundance of carbon. Having described the principal experiments and opinions of chemists on the cause of the difference of colour between venous and arterial blood, the third part of this article of respiration will give an account of the different systems on animal heat.

Animal Heat.—The origin and causes of heat in the animal body have been subjects of discussion from the ^{Opinions of it.} earliest ages; but the ignorance of the ancients in science, and their superstition, which is always the consequence of it, enabled them only to form extravagant and absurd ideas. It is well known how greatly they were inclined to attribute every thing they could not understand to supernatural power, and this propensity pervaded the wisest. We are told that even the great father of medicine, Hippocrates, ^{Hippocrates.} was not devoid of this weakness. He considered heat as a mystery, and even bestowed upon it several of

Galen.

the attributes of the Deity. "What we call heat," says he, "appears to be something immortal." We learn from Galen that the hypothesis amongst some physicians in his time was, that animal heat depended on the motion of the heart and arteries; and as they looked upon this motion to be innate, they considered that heat was likewise so: this hypothesis however he rejects; and, being a peripatetic philosopher, he accounts for it according to that system.

Helmont.

Amongst the moderns, different authors have amused themselves and the world by inventing many fanciful theories on this subject. Thus Van Helmont and Sylvius attributed animal heat to the effervescence which they thought took place in the intestinal canal from the mixture of the pancreatic juice and the bile. This notion appears to have originated from having observed that a degree of heat was produced from the mixture of certain bodies, which sometimes amounted to actual inflammation. Others attributed it to the same cause; but disagreed as to the place where this mixture happened, and of the nature of the fluids of which it consisted.

Accounted
for by mix-
ture.

Another opinion, which continued nearly two centuries, was that of the mixture of acids and alkalis; it was imagined that acefcent fluids, when taken into the stomach, met with others of an alkaline nature already prepared; and this gave rise to the heat peculiar to the animal body.

Fermenta-
tion.

After the absurdity of explaining the phenomena of the human machine by chemical mixture had been perceived by physiologists, it was succeeded by fermentation. It had been observed that fermentation was productive of heat, and as it was the fashion to explain the phenomena which took place in the vital functions by fermentation, they thought they could not do better than to attribute animal heat to the same cause; and although some of them modified their conjecture respecting the peculiar species of

fermentation, it was chiefly confined at last to the putrefactive, more especially as it was supposed that process took place during digestion. Soon after the immortal Harvey had explained the circulation of the blood, the mechanical generation of animal heat took its rise; and so certain were physiologists of its truth, that they looked upon it almost as capable of mathematical demonstration. They first conceived this opinion from observing that animal heat generally keeps pace with the state of the circulation; that when the heart and arteries beat high and quick, a great degree of heat is produced: on the contrary, when their action becomes more faint and languid, the animal heat is likewise diminished. There was, however, one point in which the mechanical physiologists could not agree, *i. e.* whether it were occasioned by the attrition of the blood against the vessels which contain it, or by the internal agitation and friction of the particles against each other. Hence it gave rise to various conjectures: many ingenious arguments were brought in support of each hypothesis; but, as facts could not determine the point, it fell, as most other hypotheses do, for want of proper evidence.

Mechanical means.

According to Dr. Mortimer, animal heat arises from the phosphorus and air which the animal fluids contain. He thinks these lie in a dormant state until brought into contact, which is effected by means of the circulation; and if it were not for the abundance of aqueous humours in animals, he alleges that incenseptions would frequently happen.

Opinion of Dr. Mortimer.

According to Douglas, animal heat arises from the friction of the globules in their circulation through the capillary vessels. Stevenson says that it is owing to the same process by which our aliment and fluids are perpetually made to undergo some alteration. According to Franklin, the fluid fire, as well as the fluid air, being at-

According to Douglas.

tracted by plants in their growth, and consolidated with the other materials of which they are composed, after being digested, and having undergone a kind of fermentation in the vessels, part of the fire and air recovers it's fluid active state again, and diffuses itself over the body, which is the animal heat.

Cullen.

A more accurate and extensive knowledge of the human œconomy soon saw into the futility of such methods of argument, and a more ingenious hypothesis perhaps than had hitherto appeared was attempted by Dr. Cullen, which he delivered in the form of little more than a conjecture. He was of opinion that the difference of temperature in different animals is owing to a difference in the vital principle; so that, although the velocity of the blood may be the same in a frog as in a man, yet, in consequence of the variety in the vital principle, the heat produced may be different; hence he supposes the principle of life has the power of generating heat or cold.

The doctrine of Stahl in fashion. Opinion of Black.

The phlogiston of Stahl now came more into fashion, and served to explain the origin of animal heat. Dr. Black having observed that animals which respire are of all others the warmest, and that there exists a striking and close connexion between their state of respiration and their degree of heat, was induced to conclude that animal heat is generated in the lungs by the action of the air on the phlogiston or principle of inflammability, in a manner not dissimilar to what he supposed to take place in actual inflammation, and that it is diffused by the circulation over the rest of the system. This opinion was defended by many arguments.—1. It was said, that since a quantity of mephitic phlogisticated air is known constantly to exhale from the lungs, and that atmospheric air, by passing through the lungs, acquires the same properties as by passing through fuel in actual inflammation, or by being exposed to any other process of

phlogification, it is obvious that the change the common air undergoes in both cases ought to be attributed to one and the same cause, viz. it's combination with phlogiston.

2. This hypothesis has been supported by urging, that the celerity with which the principle of inflammability is separated in respiration, is very closely connected with the degree of heat peculiar to each animal. Thus man, birds, and quadrupeds, vitiate air very fast; serpents and all the amphibious species, very slowly; and the latter are of an inferior temperature to the former, and breathe less frequently. 3. The most ingenious and cogent argument which the defenders of this theory have used is, that no heat is generated till the function of respiration takes place; for the foetus in utero derives all it's heat from the mother.

Against this theory, Dr. Leslie brings the following objections. 1st. That there are various proofs of the impossibility of the lungs being the source or elaboratory of animal heat, since animals without organs of respiration generate heat, and even those fishes which are destitute of gills appear, from various experiments, to be warmer than the ordinary temperature in which they live: hence respiration is not absolutely necessary for the production of animal heat. 2. If animal heat be generated solely in the lungs, it can only be communicated to the rest of the body by the arterial system, and the heat must decrease as it recedes from it's supposed centre. But it is more conformable to facts, that the venous blood is, if not warmer, at least as warm as the arterial; and according to Dr. Stevenson the thermometer immersed in flowing venous blood rises several degrees higher than that placed in the arterial, whilst there is no experiment to show the temperature of the blood to be higher in the left ventricle than in the right; which would be the case if all the animal heat was generated in the lungs. 3. Having thus

Opposed by
Dr. Leslie.

rendered it improbable that the generation of animal heat should be entirely confined to the lungs, Dr. Leslie endeavours to show that the vital fluid, far from acquiring all its heat in the pulmonary system, communicates no inconsiderable portion of what it has received in the course of circulation to the air, alternately entering and issuing from that organ. Were the blood heated in the lungs, their function would be less necessary in a warm than in a cold atmosphere: but it is known that when the air is extremely hot a person breathes full and quick to become cool, and in intense cold respiration is slow and languid; which would not be the case if the blood was heated in the lungs by the action of the air upon it. The air appears rather to diminish than increase the animal heat by carrying off phlogiston from the lungs: hence Dr. Duncan compared respiration to the blowing of bellows on a hot body; in both cases a considerable degree of heat is communicated to the air. Dr. Leslie having thus brought his arguments against the theory of Dr. Black, and after showing that heat, though *generated*, cannot accumulate in the foetus, erects another theory in its place, which depends upon the following positions:

Opinion of
Dr. Leslie.

1. That the blood contains phlogiston.
2. That this phlogiston is evolved, extricated, or brought into a state of activity and motion, by the action of the blood-vessels to which it is subjected in the course of circulation.
3. That the evolution of phlogiston is a cause which throughout nature produces heat; whether that heat be apparently excited by mixture, fermentation, percussion, friction, inflammation, ignition, or any similar cause.
4. That this heat, produced in consequence of the evolution of phlogiston from the blood of different animals, is in all probability equal to the highest degree of heat these animals in any case possess. To this theory of

Dr. Leslie succeeded that of Dr. Adair Crawford, who proved the fundamental principle Leslie laid down, viz. that the venous blood is warmer than the arterial, to be false. He likewise appears to be the first who attempted to ascertain, by direct experiment, the cause of animal heat.

Dr. Crawford, who in his general doctrine of heat Theory of, Crawford. seems to agree with Dr. Irwin of Glasgow, begins with an explanation of his terms. The words *heat* and *fire* he tells us are ambiguous. *Heat* in common language Heat. has a double signification: it is used indiscriminately to express a sensation of the mind, and an unknown principle, whether we call it a *quality* or a *substance*, which is the existing cause of that sensation. The latter, with Dr. Irwin, he calls *absolute heat*, the other *relative heat*. It therefore appears that *absolute heat* expresses in the ab- Absolute. tract that *power* or *element*, which, when it is present to a certain degree, excites in all animals the sensation of heat; and *relative heat* expresses the same power, con- Relative. sidered as having a relation to the effects by which it is known and measured; for instance, such as the effect it produces upon an instrument called a thermometer, employed in measuring it. It has been found by experiment, that in bodies of different kinds the quantities of absolute heat may be unequal, though the temperatures and weights, or their relative heat be the same. Thus, if a pound of water and a pound of diaphoretic antimony have a common temperature, the quantity of absolute heat contained in the former is nearly four times that contained in the latter. When the principle of heat is considered relatively to the whole quantity of it contained in bodies of different kinds, but which have equal weights and temperatures, it is termed *comparative heat*. If, for example, the tem- Compara- tive. peratures and weights being the same, the whole quantity of heat in water be four times as great as that in an-

timony, the comparative heats of these substances are said to be to each other as four to one. The comparative heats of bodies of equal weights and temperatures are greater or less in proportion, as less or greater alterations are produced in their temperatures by equal quantities of absolute heat. Thus, the same quantity of heat which raises a pound of water one degree is sufficient to raise a pound of mercury 28 degrees: hence the comparative heat of water is to that of mercury as 28 to 1. As equal weights of heterogeneous substances are found to contain unequal quantities of absolute heat, there must be certain essential differences in the nature of bodies, from which *some* have the power of collecting and retaining that element in greater quantity than others. These different powers are called the *capacities* of bodies for containing heat: thus, if a pound of water contains four times as much absolute heat as a pound of diaphoretic antimony at the same temperature, the capacity of water for containing heat is to that of antimony as four to one. Such are the principal definitions Dr. Crawford has laid down. He then gives some general facts respecting heat, and afterward begins to examine animal substances, so as to produce a theory upon animal heat.

Capacities
of bodies
for contain-
ing heat.

On making experiments with animal substances respecting their comparative heats, he found that arterial blood contained a greater quantity of absolute heat than water, which composed so large a portion of it; for, taking water as a standard at 1.000, arterial blood was 1.03. The remarkable accumulation of heat in this last fluid led Dr. Crawford to suspect it absorbs heat from the air in the process of respiration; and he was much confirmed in his suspicion by the following considerations:

Arterial
blood con-
tains more
heat than
water.

Considera-
tions in con-
sequence.

1. Those animals furnished with lungs, and which continually inspire fresh air in large quantities, have a tem-

perature considerably higher than the surrounding atmosphere, whilst animals without respiratory organs are nearly of the same temperature with the medium in which they live.

2. Among hot animals, those are warmest which have the largest respiratory organs, and which consequently breathe the greatest quantity of air in proportion to their bulk, such as birds.

3. The degree of heat in the same animal is in some measure proportionable to the quantity of air inspired in a given time: thus the animal heat is increased by exercise, or whatever accelerates respiration.

From these he was led to examine the subject of animal heat more particularly, the result of which is comprehended in the following propositions:

Propositions from a particular examination of animal heat.

1. The quantity of absolute heat contained in pure air is diminished by the change it undergoes in the lungs of animals, and the quantity of heat in any kind of air fit for respiration is nearly proportional to its power in supporting animal life.

2. The blood which passes from the lungs to the heart by the pulmonary vein contains more absolute heat than that which passes from the heart to the lungs by the pulmonary artery.

3. The comparative quantities of heat in bodies supposed to contain phlogiston are increased by the changes they undergo in the processes of calcination and combustion.

4. The colour of the venous blood of a living animal approaches more nearly to that of the arterial in a warm than in a cold medium; less air is phlogisticated, in a given time, in the former than in the latter situation; and the heat produced by the respiration of an animal is nearly equal to that produced by the burning of wax or charcoal, the quantities of pure air consumed being the same.

Explanation
of animal
heat from
Dr. Crawford's ex-
periments.

Dr. Crawford, from experiments made on the comparative heats of different airs and animal substances, so as to explain the phenomena of respiration and animal heat, found that water being the standard at 1.000, inflammable air was 21.4000; dephlogificated air 4.7490; atmospherical air 1.7900; aqueous vapour 1.5500; fixed air 1.0454; phlogificated air 0.7936; arterial blood 1.0300; venous blood 0.8928; fresh milk of the cow 0.9990; hide of an ox with the hair 0.7870; lungs of a sheep 0.7690; lean of the beef of an ox 0.7400:—he therefore forms an estimate of the quantity of heat yielded by the purer part of atmospherical air when it is converted into fixed air and aqueous vapour during respiration, and also of that which is absorbed during the conversion of venous into arterial blood by the same process, explaining his theory of animal heat in the following manner.

From having proved that the comparative heat of pure air is to that of the fixed air and aqueous vapour, into which it is changed in the lungs, as three to one, the same heat which raises the pure air one degree will raise the fixed air and aqueous vapour three degrees; and, consequently, the same heat which raises pure air any given number of degrees will raise the fixed air and aqueous vapour the same number of degrees multiplied by three.

Having proved that pure air at the common temperature of the atmosphere contains 1550 degrees of heat, if a certain quantity of pure air, not in contact with any body that would immediately carry off the heat, should suddenly be converted into fixed air and aqueous vapour, the heat contained in the former would raise the latter 1550 degrees multiplied by three, or 4650 degrees; and the temperature of red hot iron being 1050, it follows that the quantity of heat yielded by pure air, when converted into fixed air and aqueous vapour, is such (if it were not dissipated) as would raise the air and vapour so changed to

more than four times the excess of the heat of red-hot iron above the common temperature of the atmosphere. If, therefore, the absolute heat which is disengaged from the air in respiration were not absorbed by the blood, a very great degree of sensible heat would be produced in the lungs.

Again, having proved that the same heat which raises venous blood 115 degrees will raise arterial only 100 degrees; the same heat which raises venous blood any given number of degrees will raise arterial a less number, in the proportion of 100 to 115, or of 20 to 23. But venous blood contains at least 1580 degrees of heat: hence, if a certain quantity of venous blood, not in contact with any body that would immediately supply it with heat, should suddenly be converted into arterial, the heat contained in the former would raise the latter only $\frac{20}{23}$ of 1580 degrees, or 1373 degrees; and consequently the sensible heat would suffer a diminution equal to the difference between 1580 and 1373, or nearly 200 degrees. But the common temperature of the blood is 96: when therefore venous blood is converted into arterial in the lungs, if it were not supplied by the air with a quantity of heat proportionable to the change it undergoes, its sensible heat would be diminished 200 degrees, or it would fall from 96 to 104 below the zero of Fahrenheit.

That animal heat depends upon the separation of elementary fire from the air in the lungs is likewise, according to Dr. Crawford, supported by experiments made in support of the third and fourth propositions. For from those of the third it appears, that when bodies are united with the inflammable principle they part with a portion of their elementary fire; and when this is again disengaged, they reabsorb an equal portion of this fire from the surrounding bodies. It also appears, from those of the fourth proposition compared with the discoveries of

Priestley and Cavendish, that when pure air is combined with the inflammable principle, in the state of light inflammable air, it is changed into aqueous vapour; but in the state of heavy inflammable air it is converted into fixed air; that wax, oil, and tallow consist chiefly of heavy and light inflammable air in a solid state; that, when pure air is altered by the combustion of these substances, fixed air and aqueous vapour are produced, and the same products are obtained when that fluid is altered by the respiration of an animal. Hence it follows, that in respiration and combustion the pure air is altered in its properties by combining with the inflammable principle: and since we know that the union of these elements is universally accompanied with the extrication of heat, and a large quantity of elementary fire is disengaged from the air in the combustion of oleaginous substances in particular, it may be concluded, that in the process of respiration a similar extrication of fire takes place; and this is confirmed by some experiments, the results of which are, that when equal quantities of air are changed by the respiration of an animal, and by the combustion of a wax taper, the quantities of sensible heat produced are nearly the same.

It has also been proved, that the change the blood undergoes during its circulation in the lungs is similar to that which solid bodies undergo when melted; *i. e.* their capacities are increased: and since when solid bodies are melted a quantity of heat is absorbed, it may be concluded, that when venous is changed into arterial blood a similar absorption takes place.

Lastly, experiments show, that when an animal is placed in a cold medium, the venous blood acquires a deeper hue, and a greater quantity of air is altered by respiration in a given time than when it is in a warm medium. Now, Dr. Priestley has proved that the livid colour of the venous blood depends upon its union with

the inflammable principle: hence, the more the blood contains, the more it phlogisticates the air in the lungs in a given time, and a greater quantity of elementary fire is absorbed, in proportion as the animal is in a medium of a low temperature. Hence, the quantity of heat separated from the air, and absorbed by the blood, is in all cases proportioned to the necessity: the elementary fire is therefore the true cause of animal heat.

Animal heat, therefore, depends upon a process resembling a chemical elective attraction. The pure air is received into the lungs containing a great quantity of elementary fire; the blood is returned from the extremities impregnated with the inflammable principle; the attraction of pure air to the latter principle is greater than that of the blood. This principle will therefore leave the blood to combine with the air: by this combination the air is obliged to deposit a part of its elementary fire; and as the capacity of the blood is at the same moment increased, it will instantly absorb that portion of fire detached from the air. The arterial blood, in its passage through the capillary vessels, is again impregnated with the inflammable principle; hence its capacity for heat is diminished, as is shown by experiments in proof of the second proposition. It will therefore, in the course of circulation, gradually give out the heat it received in the lungs, and diffuse it over the whole system. Thus, in respiration, the blood is continually discharging the inflammable principle and absorbing heat, and in circulation continually imbibing this principle and emitting heat. But as heat is not proved to be a substance, Dr. Crawford does not mean to say that elementary fire is capable of chemical combination; or to affirm that heat is disengaged from the air in respiration by means of a double elective attraction: he only gives conclusions deduced from facts and experimental testimony; and if it be ad-

Source of
animal heat,
and the pro-
cess of its
production.

mitted as a certain truth, that a *diminution* is produced in the quantity of heat contained in the air, and an *increase* in it contained in the blood, by respiration, it will not be denied that, in this process, heat is continually passing from the air to the blood.

To this may be added, that as the blood by it's impregnation with the inflammable principle has it's capacity for heat diminished, so, on the contrary, those parts of the system from which it receives this principle will have their capacity for heat increased, and will consequently absorb heat.

The capacities of those parts which give out the inflammable principle are not however so changed as to absorb all the elementary fire during circulation; for then it would be necessary to have recourse to some other cause to account for the sensible heat produced in the circulation: hence, a part of the fire separated becomes redundant. This is likewise supported by an extensive analogy; for the process by which the arterial blood is phlogistified during it's passage through the minute vessels is similar to that by which pure air is phlogistified in the combustion of oleaginous substances. In the latter process, the inflammable principle is separated from an earthy basis, and combined with the air; in the former, it is separated from the putrescent parts of the system, and combined with the blood. In both cases, the capacity of the body which parts with it is increased, and that of the body which receives it, diminished; and since in combustion a quantity of heat becomes redundant, the conclusion is, that the same happens in circulation. It must, however, be granted, that those parts of the system which communicate the inflammable principle to the blood have their capacity increased, and therefore a part of the fire separated from the blood will be absorbed; and to this cause is perhaps owing, that less heat is produced by an animal than by the burning of a wax taper, the quantities of air

Arterial
blood phlo-
gistified in
the same
way as pure
air in com-
bustion.

consumed being equal; for, probably, the putrescent juices as soon as they have given the inflammable principle to the blood fly off in the form of insensible perspiration, carrying a part of the fire detached in circulation: the portion of fire thus absorbed, however, is not very considerable, as appears from the quantity of heat which becomes sensible in the animal body. It therefore appears, that the blood in it's progress through the system gives out the elementary fire it had received in the lungs from the air, a small portion of which fire is absorbed by those particles which impart the principle to the blood, and the rest becomes redundant, or is converted into moving and sensible heat.

Part of the
fire redun-
dant.

Dr. Crawford then recites the principal facts relating to animal heat in the following manner:

Principal
facts rela-
ting to ani-
mal heat.

1. He is of opinion, that the doctrine just stated explains the reason why breathing animals have a higher temperature than those which are not furnished with respiratory organs; for it has been proved, that the former are continually absorbing heat from the air; and it is probable, that to provide an apparatus for the absorption of heat, was the chief purpose of nature in giving to so great a part of the animal creation a pulmonary system, and a double circulation. The quantity of air changed by a man in a minute is found by experiment to be equal to that altered by a candle in the same space of time; and hence a man is continually deriving as much heat from the air as is produced by the burning of a candle. Naturalists have remarked, that the cold animals have also the power of keeping themselves at a temperature somewhat higher than the surrounding medium. It is probable that in these animals the aliment contains more absolute heat than the blood; for, as the blood during it's passage through the capillary vessels has it's capacity diminished, and hence is obliged to give out a part of it's

Animals
with respi-
ratory or-
gans have a
higher tem-
perature
than others
which have
not.

absolute heat, the source from which it is again supplied, these animals having no lungs, and consequently a want of respiration, is perhaps the aliment.

The production of cold in the animal body.

2. From the experiments of Dr. Fordyce made in heated rooms, it appears that the animal body has, in certain situations, the power of producing cold, or of keeping itself at a lower temperature than the surrounding medium. This could not arise solely from evaporation from the surface, as some have supposed, as the Doctor remained in moist air heated to 130 for 15 minutes, when the thermometer stood at 100 under his tongue, and streams of moisture ran from his whole body, from the condensation of vapour, as appears from a similar condensation on the surface of a Florentine flask filled with water at 100. He found a dog could live without much inconvenience a considerable time in air at 260, the body of the animal being never raised more than two degrees above the natural standard. That this generation of cold does not arise solely from evaporation, appears from some experiments made by Dr. Crawford upon living and dead frogs. A living and dead frog, equally moist and nearly of the same bulk, the former being at 67, the latter at 68, were laid upon flannel in air raised to 106. Two sensible thermometers were placed in contact with the skin under the axillæ, and the order of cooling was observed for 25 minutes.

Minutes.		Air.	Dead Frog.	Living Frog.
In	1	—	70½	67½
	2	102	72	68
	3	100	72½	69½
	4	100	72½	69½
	25	95	81½	78½

The thermometers being introduced into the stomach, the internal heat was found to be the same with that at the surface. Hence the living frog acquired heat more slowly than the dead one. A living and dead frog were

taken at 75, and immerfed in water at 93, the living frog being placed in fuch a fituation as not to interrupt refpiration.

	Minute.	Dead Frog.	Living Frog.
In	1	85	81
	2	$88\frac{1}{2}$	85
	3	$90\frac{1}{2}$	87
	5	$91\frac{1}{2}$	89
	6	$91\frac{1}{2}$	89
	8	$91\frac{1}{2}$	89

Since therefore living frogs have the power of producing cold in warm water, as well as in warm air; and fince the human body has the fame power in a moift as well as in a dry air; we may conclude that this power does not folely depend upon evaporation. Dr. Crawford therefore explains it as follows :—It appears from experiment that the capacity of the blood for containing heat is fo much increafed in the lungs, that if it's temperature were not fupported by the heat feparated from the air in refpiration, or the parts adjacent, it would fink 200 degrees. Hence, if evaporation from the lungs be fo much increafed as to carry off all the heat detached from the air, the arterial blood, when it returns by the pulmonary vein, will have it's fenfible heat greatly diminifhed, and will confequently abforb heat from the veffels in contact with it and the neighbouring parts. The heat thus abforbed in the greater veffels will again be extricated in the capillaries, where the blood receives a frefh addition of the inflammable principle. If in this cafe the blood, during each revolution, were to be equally impregnated with it, the whole effect of the above procefs would be to cool the fyftem at the centre, and convey the heat to that part of the body where it can be infantly carried off by evaporation. But it appears that, when an animal is placed in a heated medium, the blood is lefs impregnated; for the

venous blood in this case becomes gradually paler and paler, till it is nearly like arterial; and it is proved by Dr. Priestley, that the livid colour depends upon combining with the inflammable principle in the minute vessels. Since, therefore, in a heated medium, it does not assume the same livid hue, we may conclude it does not take in an equal quantity of the phlogistic principle; and this conclusion is confirmed by experiments, which prove that the quantity of air an animal phlogisticates, in a given time, in a warm medium, is less than in a cold medium. It follows, from these facts, that the quantity of heat given by the blood in the capillaries will not equal what it had absorbed in the greater vessels, or positive cold will be produced. For example:—If the blood in passing to the capillaries absorb from the greater vessels a quantity of heat as 200, and if, from not receiving a less impregnation of the phlogistic principle than formerly, it give off at the extreme vessels a quantity of heat only as 150, a degree of refrigeration will be produced as 50; and this refrigerating cause will continue to act while the colour of the venous is approaching the arterial, till it comes the nearest possible; after which it will cease to operate. Thus, when animals are placed in a warm medium, the same process which formerly supplied them with heat becomes for a time the instrument of producing cold, and probably preserves them from such rapid alterations of temperature as might prove fatal to life. Upon the whole, the increased evaporation from the surface, and the diminution of that power by which the blood in its natural state is impregnated with the phlogistic principle, seem to be the great causes on which the refrigeration depends. By the first the animal is cooler at the surface, and by the second an accumulation of heat at the centre is obviated.

The power which animals possess of cooling themselves at the centre, when placed in a medium above their natu-

ral heat, seems peculiarly necessary to preserve life. For, as the heat received at the surface is speedily, in such cases, carried towards the internal parts by the reflux of the heated fluids, if it were not absorbed and rendered insensible by the change of the blood in the lungs, the central heat would probably soon be so increased as to destroy the vital principle.

3. The reason is now evident why animals preserve an equal temperature during the great variations of the heat of the atmosphere, arising from the changes of weather and difference of season and climate.

The equal temperatures of animals.

From experiments in proof of the fourth proposition it appears, that in respiration the difference between the purity of the inhaled and expired air is increased by exposing the animal to cold; and likewise the difference between the colour of the arterial and venous blood is augmented from the same cause. But the quantity of fire separated from the air must be in proportion to these differences. For, as the extrication of heat from that element is produced by its phlogification, the more completely a given portion of air is phlogified, the greater will be the quantity of heat detached from it. The same with respect to the phlogification of the blood. It follows, as soon as by exposure to cold an unusual dissipation of the vital heat is produced, the blood will begin to be more deeply phlogified; hence will give more of it to the air, and in return get a greater portion of fire. In summer the reverse will take place; the air will be less tainted by respiration, a smaller portion of the phlogistic principle will be attracted by the blood, and the quantity of fire absorbed will be proportionably diminished. Hence the heating and cooling powers in the animal body are so adjusted to each other, as to produce an equal effect; and consequently the law by which animals maintain an uniform temperature is similar to that by which the temperatures of bodies

become fixed when they have arrived at the melting or freezing points. When freezing water, for example, is exposed to a cold atmosphere, the quantity of elementary fire carried off by the surrounding air is precisely balanced by what is extricated from the water at the moment of congelation. In like manner, when an animal is exposed to a cold atmosphere, the quantity of heat carried off by the circumambient medium is balanced by what is detached from the blood in circulation. On the contrary, when ice is placed in a warm atmosphere, the whole of the heat it receives is rendered insensible; and it has been shown, that when an animal is placed in a warm medium, a similar extinction of the heat takes place.

Hence the power animals possess of generating heat is in all cases proportioned to the demand. It is increased by the winter colds, diminished by the summer heats, and is totally suspended, or converted into a contrary power, as the exigencies of the animal may require.

As the quantity of air an animal phlogisticates in a warm medium is not so great as in a cold one, it follows, that in countries between the tropics the air will be less contaminated, *ceteris paribus*, by the respiration of animals than in the temperate and frigid zones; and the difference is considerable, if we recollect that the phlogistication of a given quantity of air by an animal at the temperature of 50, was found to be twice as great as that produced by the same animal in an equal time at 100. In those parts of the earth, therefore, in which the contamination of the air is increased by the influence of heat upon *dead* animal substances, that element sustains less injury from the respiration of *living* animals.

An animal is hot in proportion to the air he breathes in a given time.

4. Among different animals, those are the hottest which breathe the greatest quantity of air in proportion to their bulk; and in the same animal the degree of heat is in some measure proportionable to the quantity of air inhaled

in a given time. Hence in exercise, by the action of the muscles, the venous blood is returned from the extremities, in greater quantities than usual, to the right auricle of the heart. By the action of the heart it is determined to the lungs. The respiration is accelerated, the velocity of circulation increased, and hence a proportionable increase in the quantity of heat absorbed. The cold stage of fevers is preceded by languor, and a diminution in the action of the heart and arteries. The respiration is small, the quantity of blood which passes through the lungs in a given time is diminished; and hence less phlogiston will be discharged from the blood, and consequently less heat separated from the air. In putrid fevers, as the solid and fluid parts of the system are in a putrescent state, and consequently retain the principle of inflammability with less force, a greater quantity of this principle will be discharged from the lungs, the air will be more copiously supplied with it in the process of respiration, and will, therefore, impart to the blood a greater proportion of its absolute heat. To these causes it is probably owing, that the heat of the human body never rises so high as in putrid fevers.

5. Topical inflammation is accompanied with redness, tumour, and unusual heat. From the throbbing of the vessels, and from microscopical observations, it appears that the velocity of the blood through the part inflamed is accelerated. Hence the blood is more copiously supplied with phlogiston, and a greater quantity of heat will therefore be extricated in a given time. This heat will stimulate the vessels into more frequent and forcible contractions, by which the velocity of the blood, and the consequent extrication of heat, will be still further increased. It is on this principle that, according to Dr. Crawford, we may perhaps account for the partial heats produced by topical inflammations, and for those in hectic and nervous

The increase of heat in topical inflammation.

diseases. Heat in topical inflammations is accumulated by the increased velocity of the blood through the part inflamed, in the same manner as it is accumulated upon the fuel in combustion by directing a stream of fresh air into the fire.

Several conjectures that respiration and combustion arise from the same cause.

Mayow has already been considered as the first amongst the modern philosophers, who showed the cause of combustion and respiration to be the same. It however appears that several had preceded him, if not in experiment, at least in conjecture. Something was supposed to exist in the air, equally necessary to respiration and combustion, so early as the beginning of the seventeenth century. Pegelius, in a book entitled *Theaurus Rerum selectarum, magnarum, dignarum, utilium, suavium, pro Generis humani Salute oblatus*, Auct. Magno Pegelio, 1604, says, “*quod aer respiratione attractus, corpus totum subintret, et motum continue cum vita restituat et sustentet, et illud quod hinc continue exterius defluit et quod per os iterum ex interioribus seu ex toto egreditur, restituat et subimpleat; non secus quam ignis ex aere attracto et corpora excalefacta et ardentia penetrante subinde generatur et sic alitur.*” We are informed by Dr. Thornton that Hooke, in his *Micrographia* printed in Nov. 1664, had made some discoveries relative to the use of air in combustion and respiration, by which he preceded Mayow nearly four years; “the air being a subject,” says Hooke, “which (although all the world has hitherto lived and breathed in, and been conversant about) has yet been so little explained, that a diligent inquirer will be able to find but very little information from what has been (till of late) written upon it: but being once well understood, it will, I doubt not, enable a man to render an intelligible, nay, probable, if not the true reason of all the phenomena of fire, which, as it has been found by writers and philosophers

“ of all ages, a matter of no small difficulty, as may be
 “ sufficiently understood by their strange hypotheses and
 “ unintelligible solutions of some few phenomena of it ;
 “ so will it prove a matter of no small concern and use in
 “ human affairs, when I come to show the use of *air in*
 “ *respiration*, and for the preservation of the life ; nay,
 “ for the conservation and restoration of the health and
 “ natural constitution of mankind, as well as all other
 “ aerial animals ; as also the uses of this principle or
 “ property of the air in chymical, mechanical, and other
 “ operations.”

A third instance of the process of respiration having been compared to combustion, is in the collection of Wedel, published at Jena in 1686 ; the title is, “ G. W. Wedel Exercitat. Med. Physiol. &c. Jena, 1686,” in which is a dissertation, “ Von der thierischen Wärme, Nutzen des Athemholers, &c. ;” and finally, this resemblance was observed by Dr. Black.

It appears, therefore, that the similarity between combustion and respiration, or that the principle was the same that was consumed in both, had already been noticed, although in a vague manner ; but the properties and nature of this cause, which exists in the atmosphere, had escaped their observation ; and hence the most necessary part of the function of respiration was unknown ; for, before any real light could be thrown upon this obscure subject, several facts were necessary to be acknowledged.

1st. That caloric (matter of heat) is a constituent part of fluids, and that it is to this principle they owe their expansibility, their elasticity, and several other properties we know they possess.

2d. That the atmospheric air is composed of two æri-form fluids, *i. e.* of about one fourth part of vital air, and three fourths of azot gas.

3d. That the basis of vital air, oxygen, is a principle

common to all acids, and that it is this which constitutes their acidity.

4th. That carbonic acid gas (fixed air) is the result of the combination of about 72 parts in weight of oxygen, and of 28 parts of carbon (pure charcoal).

5th. That less caloric enters into the composition of a given volume of carbonic acid gas, than of an equal volume of vital air; and that it is on this account that caloric is disengaged during the combustion of carbon, *i. e.* during the conversion of vital air into carbonic acid gas by the addition of carbon.

6th. Lastly, that water is not an element, nor a simple substance, as the ancients supposed, but that it is composed of 14.338 parts of oxygen, and of 85.668 parts of hydrogen.

These facts being established, a great deal was done in the explication of the production of animal heat.

From the supposition of the Stahlans, air was phlogisticated by respiration as well as by combustion; but Lavoisier announced in 1777, in a memoir read to the Academy, that respiration was a slow combustion of a portion of carbon which the blood contains, and that animal heat is caused by a portion of the caloric that is disengaged at the moment of the conversion of the vital air of the atmosphere into carbonic acid gas, as happens in the combustion of charcoal; but he offered it only as a very probable conjecture: whilst Crawford, who had discovered the cause of it nearly at the same time as Lavoisier, and in the same year, published his very interesting work in 1779, in which he collected a number of experiments to realize this suspicion. In 1788 a very enlarged edition of this work appeared, from which the account given of his doctrine is taken, and from which it seems that Dr. Crawford ably supports the phlogistic system.

The experiments which Lavoisier and de la Place

published in 1780 confirm the opinion the first chemist had conceived, and totally overturned the theory of phlogiston. To determine the effects of respiration and combustion upon air, these two chemists introduced a guinea-pig under a glass vessel containing 248.01 inches of pure air, and let it remain there an hour and a quarter. After having taken away this animal, by making it pass through the mercury, and left the interior air to become of the temperature of the atmosphere, it was reduced to 240.25 inches. Having afterwards absorbed the fixed air by caustic alkali, there remained 200.56 inches of air. In this experiment, therefore, there were 46.62 inches of pure air changed, and 37.96 inches of fixed air produced, making an allowance for the small quantity of fixed air contained in the pure air of the vessel. Now of the volume of pure air thus changed, 0.814 will be its volume diminished by respiration; whilst in the combustion of charcoal the volume of air is diminished in the ratio of 1 to 0.74828. This difference may in some degree arise from the difference of measure, but perhaps more so from letting a little of the exterior air penetrate into the vessel on introducing the animal.

Effects of
respiration
and combustion
compared
by Lavoisier
and de la
Place.

The weight of the fixed air produced in the above experiment is 26.572 grains; from which it follows, that in the space of ten hours the animal would have produced 212.576 grains of fixed air.

On determining the quantity of fixed air produced by a guinea-pig in common atmospherical air, it was found to amount to 236.667 grains in ten hours; which differs about one ninth from the preceding experiment, arising probably from the difference of size in the two animals.

A third experiment, made upon a guinea-pig in dephlogisticated air, afforded 226 grains of fixed air in ten hours.

On taking the medium of these experiments, and some

others made by these chemists, both in dephlogisticated and atmospherical airs, it appears that the quantity of fixed air generated by the respiration of the guinea-pig in ten hours amounts to 224 grains. Since these experiments were made at a temperature of 14 or 15 degrees, these chemists think it possible that the quantity of fixed air may be somewhat less than at a temperature of zero, which was that of the interior part of the vessels: hence, to be more exact, the products of fixed air ought to be determined at this last temperature. Having proved, by experiment, that in the combustion of charcoal the formation of one ounce of fixed air is able to melt 26.692 ounces of ice, it follows that the formation of 224 grains of fixed air ought to melt 10.38 ounces. Consequently this quantity of melted ice represents the heat produced by the respiration of a guinea-pig during ten hours.

In the experiment on the animal heat of a guinea-pig, it was taken from under the glass vessel nearly of the same heat with which it was introduced; for it is well known that the interior heat of animals is always nearly the same, but, without a continual renewal of this heat, what it possessed at first would be entirely dissipated, like that of an inanimate body: this heat therefore which it communicates to the surrounding substances, and which in this experiment was communicated to some ice placed under the vessel, of which it melted in ten hours thirteen ounces, is renewed by its vital functions. This quantity of melted ice represents, therefore, nearly the heat renewed in that space of time by respiration. Perhaps it may be necessary to subtract a couple of ounces or more, since the extremities of the body of the animal became cooled in the vessel, although the interior of the body preserved nearly the same temperature: besides, the humours evaporated by its internal heat melted, on cooling, a small

quantity of ice, and united with the water which ran from the vessel.

On deducting, therefore, about two ounces and a half from this quantity of ice, the remainder will be the quantity melted by the respiration of the animal; and if the errors which are inevitable in such experiments be considered, perhaps a more perfect coincidence between these results cannot be expected.

Hence, according to these chemists, the heat disengaged during the conversion of pure into fixed air by respiration may be considered as the principal cause of the preservation of animal heat; and if other causes concur in it's support, their effect is inconsiderable.

From these experiments these chemists conclude that respiration is a combustion, which, although very slow, is perfectly similar to that of charcoal; that it takes place in the interior part of the lungs without disengaging any sensible light, because the matter of fire, become free, is immediately absorbed by the humidity of these organs; that the heat thus extricated in this combustion is communicated to the blood which traverses the lungs, and is from thence distributed all over the system. Hence the air we breathe serves two purposes equally necessary to our preservation—it takes from the blood the basis of the fixed air, the superabundance of which would be hurtful; and the heat deposited in the lungs by this combination repairs the continual loss of heat brought about by the atmosphere and surrounding bodies.

Respiration
is a perfect
combustion.

Animal heat is nearly the same in all parts of the body; which effect appears to depend on the three following causes:

Causes of
the equality
of animal
heat.

1st. The rapidity of the circulation of the blood, which transmits immediately, even to the extremities of the body, the heat it receives in the lungs.

2d. The evaporation produced by the heat in these organs, and which diminishes the degree of their temperature.

3d. The augmentation observed in the specific heat of the blood, when it is deprived of the basis of fixed air it contains by the contact of the pure air: hence, a part of the specific heat developed in the formation of the fixed air is absorbed by the blood, its temperature remaining always the same; but when in the circulation the blood comes to receive again this basis of fixed air, its specific heat diminishes, and some heat is extricated; and as this combination is made in all parts of the body, the heat it produces contributes to support the temperature of the parts distant from the lungs nearly at the same degree as that of these organs. From this way of reasoning the chemists establish the following propositions:

When an animal is in a permanent and tranquil state, when it is able to live a considerable time without suffering in the medium that surrounds it: in general, when the circumstances in which it is do not sensibly change its blood and humours, so that the animal system after several hours undergoes no sensible variation, the preservation of the animal heat is owing, at least in great part, to the heat produced by the combination of the pure air respired by animals with the basis of the fixed air furnished by the blood.

Hence, on comparing the heat disengaged by the combustion of charcoal with the quantity of fixed air formed during this combustion, the heat developed in the formation of a given quantity of fixed air is obtained: if, then, the quantity of fixed air produced by an animal in a given time be determined, the result will be the heat arising from the action of its respiration on the air; and it only remains to compare this heat with that which supports its animal heat, and to measure the quantity of ice it

melts in the interior of the vessel: and if, as has been found by the preceding experiments, these two quantities of heat are nearly the same, it may be concluded that it is to the change of pure into fixed air by respiration that the preservation of animal heat is owing, at least for the most part.

In respiration, as in combustion, it is the air of the atmosphere that furnishes the oxygen and the caloric; but as in respiration it is the substance even of the animal, the blood, which furnishes the combustible part, if animals did not habitually repair by nourishment what they lose by respiration, the oil would soon be wanting to the lamp, and the animal would perish like an extinguished candle. There are even instances cited by authors of this combustion being so rapid as to consume the greater part of the body. Thus a female described by Wilmer, or the inflammable woman of Coventry; the countess Cornelia Bandi, near Cesena, in Romagna; another woman at Christ-church, in Hampshire; and Grace Potts, at Ipswich; were consumed by an internal fire, so eager were the principles of which they were composed to combine, as Dr. Beddoes says, with oxygen. These remarkable instances, however, of quick combustion carried on in the body are very rare.

Extraordi-
ry cases
of rapid
animal
combustion.

The proofs therefore of this identity of effects between respiration and combustion are taken immediately from experience. Indeed, the air that has been respired no longer contains, at it's departure from the lungs, the same quantity of oxygen; it contains not only carbonic acid gas, but likewise much more water than it did before inspiration. Now, since vital air cannot be converted into carbonic acid gas without the addition of carbon, or into water without hydrogen; and since this double combination cannot take place without the vital air losing a part of it's specific heat, the consequence is, that the effect of

Experiments of Seguin and Lavoisier to determine the quantity of carbonic acid gas and water formed during respiration, &c.

respiration is to extract a portion of hydrogen and carbon from the blood, and to deposit in their place a portion of it's specific caloric, which during circulation is distributed with the blood into all parts of the animal œconomy, and sustains that temperature observed in all respiring animals, and which, if nothing extraordinary happen, is nearly constant. It may therefore be said with the ancient poets, that the torch of life is lighted the moment the infant breathes; a gentle combustion, productive of the vital flame, which is only extinguished by death. Since, during respiration, a great quantity of carbon and hydrogen from the blood is converted by uniting with the oxygen of the air into carbonic acid gas and water, and consequently a great deal of caloric let loose; Lavoisier and Seguin have made some experiments to endeavour to find the quantity of carbonic acid gas and water which is formed; and as there is an aqueous emanation not only from the lungs, but also from the surface of the body, which is called *perspiration*, they were likewise desirous of knowing the quantity extricated from so large a surface, and of comparing, as near as circumstances would permit, the connexion arising between respiration, perspiration, and digestion. The invisible vapour or emanation that takes place from the surface of the body they have called *cutaneous perspiration*; and that which is extricated from the lungs at each expiration, *pulmonary perspiration*.

Sanctorius was the first who undertook to make experiments on the cutaneous perspiration: for this purpose he placed himself in a chair adapted to a pair of scales, and he determined the quantity of perspiration by the loss of weight he experienced.

Before his time, nothing but conjecture determined the effects of this cutaneous function; and although this philosopher was the first experimental inquirer on the subject, many things were wanting to make him successful.

The phenomena of respiration, and the formation of water and carbonic acid which accompanies it—the two species of evaporation, one of which is effected by solution in the air, and the other by the simple combination of caloric with the evaporated liquor, were unknown. It was not even suspected that the principal causes which influence respiration are the greater or less density of the air, its temperature, and its degree of dryness or humidity. Sanctorius, deprived of these preliminary facts, confounded all the effects which arose from his experiments.

In order to separate the cutaneous perspiration, these two chemists made use of a garment of silk, coated with elastic gum, so as to prevent the air and humidity from penetrating. When this was put on, it was tied at the top of the head by a strong ligature, whilst a tube was adapted to the mouth, so as not to let any air escape, to breathe through: hence, whatever was respired passed externally, and whatever perspired, internally.

By being weighed on entering this apparatus, and after having departed from it, the difference gave the loss of weight owing to the united effects of respiration and perspiration; and by being weighed a few instants after having entered and before departing from it, the loss of weight owing only to the effects of respiration was obtained.

The greatest difficulty which the chemist had to contend with was the separation of the products of respiration, of pulmonary and of cutaneous perspiration; for it is necessary to know, that there continually oozes into the lungs an humour separated from the blood, which filters through the membranes of the lungs, and which is composed principally of hydrogen and of carbon.

It is this humour which, being greatly divided at the moment it comes from the small extremities of the exhaling vessels of the lungs, is in part consumed by decomposing

the vital air with which it was in contact, and forms during this combustion water and carbonic acid gas. It is not astonishing that this combustion should exist in the lungs, when it is seen that dung, the nature of which approaches much to that of blood, burns at the ordinary temperature of the atmosphere, *i. e.* at 8° or 10° .

The carbonic acid gas therefore, formed during respiration, being in a fluid state, it is easily conceived how it is evacuated by the action of the lungs at the moment of expiration; but the case is not so with the water formed at the same time. It would soon accumulate in the bronchia, if nature had not the means of evacuating it, one of which is this. The air enters cool into the lungs; it departs from it with a heat nearly equal to that of the blood: now the hot air dissolves more water than cold air, and it is from this increase of caloric that it carries away with it the water existing in the lungs.

This water is of two sorts; 1. that which oozes with the carbonated hydrogen, or the water of pulmonary perspiration, properly called. 2. That which is formed by the combination of the oxygen of the air with the hydrogen of the blood, or the water of respiration.

These chemists were able to obtain the respective quantities of these two portions of water.

The apparatus they made use of was so disposed as to be able to measure, with great exactitude, the quantity of water and of carbonic acid exhaled, as well as the quantity of air before and after the experiment; for it is easily conceived, that being acquainted on the one side with the total sum of the water come from the lungs, and on the other, the quantity of carbonic acid gas formed, it would be easy to determine, by a very simple calculation, the quantity of water formed, and the quantity of water owing to the pulmonary perspiration. But in the solu-

tion of this problem, it is taken for granted, that all the carbonic acid gas disengaged at each expiration is formed in the lungs, and during circulation.

If the carbonic acid gas disengaged during expiration was in part the product of digestion, the consumption of vital air in the act of respiration must be attributed to another cause. The supposition must be, that more water is formed, either in the lungs or during circulation; and then the pulmonary perspiration would be found to be diminished by all the quantity of water which must be attributed to this formation; or it must be granted, that a part of the vital air, being absorbed in the lungs, unites during circulation with some part of our system.

The increase of menstrual power, which the air acquires by being heated in the lungs, is in general sufficient to evacuate, by way of solution, the two portions of water just mentioned; viz. that arising from the pulmonary perspiration, and that formed by the combination of oxygen and hydrogen. In this respect, nature appears to make use of some very curious means of compensation. If the quantity of water which oozes through the bronchial membranes be too abundant; if the air of respiration, already loaded with water that is formed, is not in a state to dissolve it in spite of the efforts of a more accelerated respiration, and in spite of the increase of caloric proceeding from it, which increases the menstrual power of the air; the excess is carried back again into the circulation by the absorbent vessels of the lungs, or expectorated under another form.

It is easy to conceive how all these causes must influence the phenomena of perspiration; that it is accelerated or retarded according to the necessity of the machine—that it ought sometimes to form more water, sometimes more carbonic acid gas—that, in short, the pulmonary perspiration can be augmented or diminished by an infinity of circumstances.

These chemists found, that the loss of weight of a person in an ordinary state varies from 11 grs. a minute to 32; *i. e.* in 24 hours from 1 lb. 11 oz. 4 drs. to 5lbs. comprehending the effects of cutaneous and pulmonary perspiration, and of respiration. Taking the medium, the loss of weight is 18 grs. per minute; and supposing it to continue uniformly, it will be 1 oz. 7 drs. an hour, and 2 lbs. 13 oz. in 24 hours.

	lb.	oz.	drs.
Of these 2 lbs. 13 oz. there belong to			
cutaneous perspiration - - - -	1	14	0
And to the effects of respiration - -	0	15	0
Total - -	2	13	0

On decomposing the effects of respiration, it will be found, on a medium,

1. That an individual consumes 38413 cubic inches of vital air in 24 hours, *i. e.* a little more than 22 cubic feet, or 33 oz. 1 dr. 10 grs.

2. That of this quantity there is employed to form water a little more than - - -	} 13 cubic feet,
And to form carbonic acid a little less than - - -	
	9
	22

3. That the volume of carbonic acid gas, disengaged from the lungs in 24 hours, is 14930 cubic inches, <i>i. e.</i> about 8 feet 6 cubic inches, which are composed of carbon -	} lb. oz. drs. grs.
oxygen -	
	0 5 7 0
Total - -	1 1 7 4

4. That the weight of the water, formed in the lungs in 24 hours, amounts to 1 lb. 7 oz. 5 drs. 20 grs., which are composed of

	<i>lb. oz. drs. grs.</i>			
Hydrogen	0	3	3	10
Oxygen	1	4	2	10
<hr/>				
Total	1	7	5	20

5. That the quantity of water disengaged ready formed by pulmonary perspiration, is 5 oz. 5 drs. 62 grs. in 24 hours.

	<i>lb. oz. drs. grs.</i>			
Lastly, That uniting together the water disengaged in 24 hours, by cutaneous perspiration, which amounts to	1	14	0	0
That disengaged by pulmonary perspiration	0	5	5	62
The quantity of carbon consumed in the same time	0	5	7	0
And the quantity of hydrogen	0	3	3	10
<hr/>				

The total loss of weight of a person in 24 hours is

	2	13	0	0
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These results are only to be estimated as probable. Seguin and Lavoisier have likewise observed, that without being very particular in taking daily the same quantity of nourishment; without restraining themselves to live by rule, provided excess and irregular hours of repast are avoided; the same individual, after having been increased in weight by all the aliments, returns every day, after the revolution of about 24 hours, to the same weight he had the evening before. If this effect does not take place, it is the consequence of disease.

It is by experience only that man can become ac-

quainted with nature ; and the more he interrogates her, the more will he be delighted with her wisdom. “ Our “ admiration,” says the chemist, “ cannot be fatigued “ with viewing the system of general liberty which nature appears to have been desirous to establish in every “ thing relative to the animal machine. In giving it life “ and spontaneous motion, an active energy, necessities “ and passions, she has not interdicted the use of them. “ She was even desirous that he should be free in their “ abuse, but prudent and wise ; she has every where surrounded him with regulators ; and she has added satisfiety to the superabundance of enjoyment.”

Animal machine governed by three principal regulators.

The animal machine is therefore governed by three principal regulators : *respiration*, which by operating in the lungs, and perhaps likewise in other parts of the system, a slow combustion of the hydrogen and carbon contained in the blood, produces a disengagement of caloric absolutely necessary to the support and existence of animal heat : *perspiration*, which, by occasioning a loss of the perspirable humour, facilitates the disengagement of a certain quantity of caloric necessary to the solution of this humour in the surrounding air ; and consequently prevents, by the continual coldness this disengagement produces, the individual from receiving a degree of heat or temperature superior to what is fixed by nature : and *digestion*, which, furnishing the blood with water, hydrogen, and carbon, restores habitually to the animal machine what it loses by perspiration and respiration, and afterwards rejects externally substances that are hurtful or superfluous to it.

If the causes which affect man are various, his resources are equally multiplied : his temperament is either adapted for motion or repose, for abstinence or excess of nourishment. Similar circumstances permit him to pass from an active to a tranquil life, according to his neces-

fities or his will. If he be in a state of inaction and repose, the circulation is slow as well as the respiration, he consumes less air, exhales less carbon and hydrogen from the lungs, and consequently has less need of nourishment. If he be obliged to work hard, the respiration is accelerated; he consumes more air, loses more hydrogen and carbon, and consequently has need of oftener repairing what is lost, by a greater quantity of nutrition. In running, dancing, and in all violent exercises, whatever acceleration the respiration and circulation undergo, or whatever increase there is in the consumption of air, of hydrogen and carbon, the equilibrium of the animal œconomy is not disturbed, whilst the aliments more or less digested, always more or less in reserve in the intestinal canal, supply their loss; but if the expense made by the lungs be greater than the receipt made by nutrition, the blood is deprived by degrees of its hydrogen and carbon, and disease succeeds. In this case the animal is advised of the danger by lassitude, loss of vigour, and he finds the necessity of reestablishing the equilibrium by nourishment and repose. The contrary takes place, for want of motion and exercise or the use of certain aliments, or any imperfection or vice in the organs of nutrition or respiration. In these cases, the digestion introducing into the blood more matter than the respiration can consume, an excess of carbon or of hydrogen takes place in the mass of blood, or perhaps both at the same time. Nature then strives against this alteration in the humours; and if she cannot recover the equilibrium by a more frequent respiration, disease is the consequence.

“Whilst,” say these two chemists, “we only considered the consumption of air in respiration, the lot of the rich and the poor was the same, for the air belongs to all, and costs nothing: the labourer even, from his greater energy, enjoys more completely this

“ gift of nature : but since experience has proved re-
 “ spiration to be a real combustion, that consumes at
 “ each instant a portion of our substance, that this con-
 “ sumption is the greater in proportion as the circulation
 “ and respiration are accelerated, that it increases accord-
 “ ing to the more laborious and active life of the indi-
 “ vidual—a multitude of moral reflexions arise of them-
 “ selves from such effects. By what fatality happens it
 “ that the poor man, who lives by the sweat of his brow,
 “ and is obliged to expend the force which nature allots
 “ him, consumes more than his idle neighbour, whilst
 “ this last has less need of repairing ?”—“ Why,” ex-
 claim these humane chemists, “ by a shocking con-
 “ tract, does the rich man enjoy an abundance which is
 “ not physically necessary for him, and which would
 “ seem to be destined for the daily labourer ? Let us
 “ not however calumniate Nature, and accuse her of
 “ faults that undoubtedly belong to human institutions,
 “ and which are perhaps not to be separated from them.
 “ Let us be content to bless philosophy and humanity,
 “ which unite to procure us superior enjoyment and
 “ happiness, and add to those of the indigent.”

This result of forces continually varying and conti-
 nually poisoning each other, which are observed at each
 moment in the animal œconomy, is truly to be admired.
 Man, in this respect, has been more favoured by nature
 than any other animals ; he lives equally in all tempera-
 tures and in all climates : if he finds himself in a cold cli-
 mate, the contact of the air with the lungs, from it's
 greater density, becomes more considerable ; more air is
 decomposed, more caloric disengaged, which repairs the
 loss caused by the external cold ; whilst the perspiration
 diminishes, evaporation becomes less, and consequently
 the cold.

If he passes into a hot climate, the contrary effect takes

place. The air being less dense, it's contact with the blood is less considerable; less air is decomposed, less caloric is disengaged, a more abundant perspiration is established, a greater quantity of heat taken away; and it is in this manner that an almost uniform degree of heat is observed in animals that breathe, which is about 32° of Reaumur.

Whilst the variation of the effects does not pass over the limits assigned by nature, whilst the means of compensation she employs are sufficient, the animal is in a state of health. But if the respiration takes more or less hydrogen and carbon by the lungs, than digestion can supply; if the perspiration and frigidity it occasions in concert with the exterior air do not take away all the caloric arising from the decomposition of the vital air in the lungs, or in any other part of the system; if, in short, throughout, the receipt is not equal to the expense, the animal machine is soon disturbed, and the blood changes it's quality, either from excess or want of hydrogen and of carbon, or both at the same time.

These two philosophers therefore, Crawford and Lavoisier, agree in looking upon the pure air as the principal source of the heat extricated in combustion and respiration: but there appears to be an essential difference in their opinions, which consists in this, that Lavoisier thinks, that the heat, disengaged during these two processes, is combined with the pure air; and that this fluid owes it's aëriiform state to the expansive force of this combined heat: instead of which, according to Crawford, the matter of heat is in a free state in the pure air; and it is only disengaged, from the pure air losing a great part of it's specific heat on combination. Crawford supports this assertion by experiments, by which he finds the specific heat of pure air to be 87 times greater than that of common water.

Difference
between
Lavoisier
and Crawford.

Girtanner.

Girtanner differs in opinion from Lavoisier and Crawford: he believes, that during respiration one part of the oxygen of the vital air combines with the venous blood, the deep colour of which it changes to a vermilion; that a second portion of the oxygen unites to the carbon contained in the carbonated hydrogenous gas, which exhales from the venous blood, and forms carbonic acid gas; that a third portion of the oxygen unites to the carbon of the mucus which the lungs contain in large quantity, and which is continually decomposing. This part likewise forms carbonic acid gas. A fourth part of the oxygen combines with the hydrogen gas of the blood to form water, which exhales during respiration. The caloric which the decomposed vital air contained *remains in part united* to the oxygen and to the blood: hence the quantity of specific heat of the arterial blood, which is greater than that of the venous; another part of the caloric enters into the combination of the carbonic acid gas; and, lastly, a third part produces the necessary temperature for the formation of water, by the combination of hydrogen and oxygen gases: consequently the *effects* of respiration should be,—

1. The venous blood loses the carbonated hydrogenous gas it contains, and absorbs oxygen gas, which gives it a vermilion colour, such as it gives to metallic oxyds, to the nitrous acid, and to several other substances with which it is combined.

2. The capacity of the blood is augmented, because oxygen increases the capacity of all substances with which it unites.

3. The oxygen gas of the atmosphere is in part absorbed by the venous blood, partly changed into carbonic acid gas, by the carbon of the blood and that of the mucus of the lungs, and partly into water by the hydrogen gas of the blood, and the great quantity of caloric become free.

The *products* of respiration should be,

1. A fluid animal oxyd; 2. carbonic acid gas; 3 water; 4. a small quantity of caloric become free.

Hence it follows, that respiration is a process exactly analogous to combustion and the oxydation of metals; during circulation the blood loses its oxygen, and becomes loaded with carbonated hydrogenous gas, by means of a double affinity; during the distribution of oxygen through the system, the caloric united to this oxygen becomes free, and produces animal heat; and the greater capacity of arterial blood for caloric is only owing to the oxygen to which it is united in the lungs.

Another opinion respecting the process of respiration ^{De la Grange.} is that of de la Grange. Considering that, if all the heat distributed through the animal system arose in the lungs, their temperature would be so very great as to cause fear lest it should constantly destroy them; and that, if the temperature of the lungs is so extraordinarily different from that of the other parts, it must have been long ago observed; he thinks he can conclude with great probability, that all the heat of the animal œconomy is separated not only in the lungs, but in all parts wherever the blood circulates. For this purpose, he therefore supposes, that the blood on passing through the lungs dissolves the oxygen of the inspired air; that this dissolved oxygen is conveyed by the blood into the arteries, and thence into the veins; and that during circulation the oxygen quits by degrees its state of solution to combine partially with the carbon and hydrogen of the blood, and form the water and carbonic acid which is extricated from it as soon as the venous blood goes from the heart in order to enter the lungs; and from this manner of explanation this chemist thinks that the small difference may be easily accounted for which is found between the temperature of the lungs and that of the other

internal animal parts, and how the caloric may arrive at the extreme parts the most distant from the lungs.

Hassenfratz. The opinion of Hassenfratz resembles the last: he thinks that caloric is not only disengaged in the lungs, but during the circulation by the union of the hydrogen and carbon of the blood with the oxygen which is intermixed with it; and as caloric is extricated during this union, and this caloric supports the animal heat; and as this union takes place for the most part during the circulation of the blood as it passes from the lungs into the arteries, and thence by the veins into the lungs, it follows, that the greatest part of the caloric is separated during this circuit. This chemist explains the experiment of Dr. Crawford, or gives the cause why the arterial blood acquires a greater specific heat than the venous; and this he says may be done two ways:—1. As all oxydated substances have a greater proportionable heat than simple substances, and as the arterial blood with respect to the venous may be looked upon as oxydated, the first must have a proportionably greater heat than the last. 2. As the oxygen in the arterial blood still contains almost all its caloric, and this is afterwards extricated in circulation by the union of the oxygen with the hydrogen and carbon of the blood—the venous, in which this combination is made, contains no more caloric, it having been disengaged and dispersed to warm all the parts through which the blood has passed: hence the venous blood ought to have comparatively less heat than the arterial. Hence the lungs are not the stove of animal heat, but the caloric in order to support it is extricated during circulation.

Gren.

According to Gren, the oxygen gas does not give up its basis to the arterial blood: he asserts, that all the water we expire is of new formation, and not separated from the blood; that consequently oxygen is only ab-

forbed for the formation of water and of carbonic acid, and that there remains none of it to combine with the blood: further, that the change of the venous into the arterial blood in the lungs does not depend upon the absorption of oxygen, but on the separation of the carbon and hydrogen; and that the arterial and not the venous blood is a stimulus to the heart.

Another theory on this subject is given by de la Me- De la Me-
therie.therie. This chemist does not believe the conclusions drawn by Lavoisier and Seguin, having found that,

1. In an ordinary inspiration, no more than from four to six inches of air enter the lungs.

2. He admits three causes of animal heat.

a. Caloric, which is disengaged from the pure air that undergoes a combination in the lungs.

b. Muscular motion; for in sleep the animal heat is less than when awake; and in local inflammation, the heat of the part is considerably raised.

c. Finally, the fermentation of animal substances in the stomach and intestines, during which fermentation caloric is disengaged; for animal matter during this process is known to be heated even to the point of inflammation.

3. Respiration likewise serves as a conductor of the electric fluid; for, from the experiments of Read, the air of an apartment in which a person has breathed for a few hours is always electrified negatively, whilst before it was in a positive state of electricity.

The last theory on respiration is that of Davy. This Davy.ingenious philosopher having from experiment laid it down as a fact that the caloric of the system of Lavoisier is not the matter of heat, or an imaginary fluid, as has been supposed; but that it may be defined a peculiar motion, or probably a vibration of the corpuscles of bodies tending to separate them; and hence may with

propriety be called *repulsive motion*; and having substituted for oxygen gas the term phos-oxygen (from $\phi\omega\varsigma$ light, $\acute{\alpha}\xi\upsilon\varsigma$ acid, and $\gamma\epsilon\gamma\epsilon\tau\epsilon\rho$ generator), to express a chemical combination of the simple substance light with the simple substance oxygen; having proved that the oxygen gas of the French nomenclators, which they have supposed to be oxygen combined with caloric, is a substance compounded of light and oxygen; and having explained the theory of combustion; he first offers some objections against the theory of respiration of the calorists.

1st. Against it's being supposed that one portion of the oxygen combines with the iron in the blood, giving the vermilion colour to the arterial blood, he asserts that iron never decomposes phos-oxygen at so low a temperature as 95° , the greatest heat of the lungs; and phos-oxygen is never decomposed by iron, without rapid combustion, flame, and great heat.

2d. Oxygen gas is never decomposed by carbon at so low a temperature as 98° , and is never decomposed without combustion, &c.

3d. There is never a decomposition of phos-oxygen by hydrogen at so low a temperature; and it is well known that this process does not take place without flame: hence the theory is false. On the contrary, Davy undertakes to prove from experiments,

1st. That phos-oxygen (light and oxygen) is not decomposed in the lungs;

2d. That phos-oxygen combines with the venous blood in the lungs;

3d. That carbonic acid and water are both liberated from the lungs during this process, either by the increase of temperature, or from the superior affinity of phos-oxygen for the venous blood.

First experiment.

A phial containing twelve cubic inches and a half was filled with very pure phos-oxygen. The medial vein of a

healthy man was opened, and the stream of blood directed into the phial. The mouth of the phial was immediately brought into contact with the arm, so as entirely to exclude all external air. The room was then darkened. As the blood flowed into it, it changed from a dark red to a bright vermilion colour. When the phial was half full, it was closed, and plunged in mercury heated to 90° . Having remained half an hour, the blood was found coagulated, and a bright vermilion colour: some drops of water were formed on the sides of the phial. When the cork was drawn, about two cubic inches of mercury rushed into the phial; from which he concluded an absorption of gas had taken place. The remaining gas was three cubic inches and one tenth of phos-oxygen, with nine tenths of a cubic inch of carbonic acid.

During the experiment no light was liberated: hence Davy supposes there was no decomposition of phos-oxygen. And as a considerable diminution of phos-oxygen took place, and the blood acquired new properties, he concludes that phos-oxygen is capable of combination with the venous blood. To prove this by analysis as well as synthesis, he made the following experiment:

A twelve-cubic-inch phial, with a pneumatic apparatus Second experiment. affixed to it, was filled with arterial blood from the carotid artery of a calf. The phial was placed in a sand bath of the temperature of 96° , and the heat gradually and slowly raised. In about ten minutes the temperature of the bath was 108° , and the blood began to coagulate. At this moment some globules of gas were perceived passing through the tube. Gas continued to pass, in very small quantities, for about half an hour; when the temperature of the sand was about 200° . The blood was coagulated, and almost black. About one cubic inch and eight tenths of gas were collected in the mercurial apparatus: of this one cubic inch and one tenth were carbonic acid, and the

remaining seven tenths phos-oxygen. Great caution is necessary in this experiment; for, if the temperature is not gradually and slowly increased, the liberated gases are carbonic acid and hydrogen.

From the above experiment it is evident that the arterial blood contains phos-oxygen; and it was before proved by synthesis that it is capable of combining with it directly: hence he concludes that phos-oxygen combines with the venous blood of the system in the pulmonary vessels.

As no light was liberated in the first experiment, it is evident there cannot be even a partial decomposition of phos-oxygen in respiration; and consequently, the carbonic acid and aqueous gas liberated cannot arise from the decomposition of phos-oxygen by the carbon and hydrogen of the venous blood—they must therefore be liberated from the venous blood. To prove this more clearly, the following experiment was made:

Third experiment.

A small sheep's bladder was filled with blood from the medial vein of a healthy woman. This blood never came into contact with any air during the experiment. The bladder was inserted in a vessel of water heated to 112° , and the gaseous products received by a pneumatic apparatus. They were carbonic acid and aqueous gas.

Respiration is therefore, according to the theory of Davy, a chemical process—the combination of phos-oxygen with the venous blood in the lungs, and the liberation of carbonic acid and aqueous gas from it. From the combination and decomposition arises an increase of repulsive motion, which, combined with that produced by the other chemical processes taking place in the system, and that generated by the reciprocal action of the solids and fluids, is the cause of animal heat.

Dr. Menzies's attempt to

An attempt has been made by Dr. Menzies, or rather he informs us he has ventured to examine, how the

ascertainment of the quantity of air usually respired may throw light on the generation of animal heat, and on the quantity of heat generated in a given time; and he is of opinion, that this can be estimated independently of any theory on the nature of heat itself.

The experiments of Crawford, Lavoisier, and de la Place, prove, when equal quantities of air are vitiated by respiration and combustion, that equal degrees of heat are evolved. Crawford found, that if an animal be shut up in a vessel surrounded with water and protected from the access of air by very soft wool, one hundred measures of air, each containing an ounce, vitiated either by this animal's respiration or by the combustion of wax or coal, communicated the following quantities of heat to 31 lbs. 7 oz. of water.

	Degrees.
100 measures of air vitiating by	The combustion of coal, gave 19.3
	————— wax, 21.0
	The respiration of a guinea pig, 17.3

But as each degree of Crawford's thermometer makes only one tenth of a degree of Fahrenheit's, it is evident, that, if a thousand such measures were vitiated by the combustion of wax and the respiration of a guinea-pig, the difference between the quantities of heat given out to 31 lbs. 7oz. of water will make 3.7 degrees of Fahrenheit's; the difference between the quantities given out by the combustion of coal and the respiration of a guinea-pig will be equal to 2 degrees of Fahrenheit's thermometer: *i. e.* the heat communicated to the water by the guinea-pig will be two degrees less than that communicated by the combustion of coal,

But from the series of experiments of Lavoisier and de la Place (*Mémoire sur la Chaleur*, 1783) it appears, that the heat communicated by the respiration of a guinea-pig,

when equal quantities of air were vitiated, was greater than that generated by the combustion of coal in the proportion of 13 to 10.3. But as contemporary authors have supposed the degree of heat said to be communicated by the guinea-pig to be somewhat exaggerated, and as the result of their experiments was almost the same, Dr. Menzies thinks the average number may be taken as a rule—the difference probably proceeding from the different construction of the instruments employed: hence it is conceived, that when equal quantities of air are vitiated, whether by respiration or the combustion of coal, nearly equal quantities of heat are generated.

As the quantity of heat generated when a given quantity of fixed air is produced by the combustion of coal has been lately demonstrated by Lavoisier (*Elements of Chemistry*, p. 101), and as the quantity of air usually respired has been ascertained: it is evident that the quantity of heat generated in the lungs, in any given time, could be also found out, if the quantity of fixed air was estimated in the air that has been once breathed.

by estimating the quantity of fixed air in respired air. First experiment.

The following experiments were made with this view: A quantity of air once respired was pressed out of an allantoid into a glass bottle inverted in water; and, lest any part of the fixed air should have been absorbed by the water, some oil was previously poured into the bottle. The bottle was then inverted into another vessel filled with caustic alkali. The barometer was in the mean time attended to, and the degree of heat marked by a thermometer. The air in the bottle was then shaken, and left in contact with the caustic alkali till all the fixed air was absorbed. Then the bottle was again plunged into the water, till the caustic alkali in the bottle and the water in the vessel were at the same height. The bottle being then stopped with a cork, and placed on it's bottom, it contained a quantity of caustic alkali, which, accurately

weighed, gave the quantity of fixed air absorbed, after some corrections being made on account of the ascent and descent of the mercury in the barometer, and the difference of temperature in the bottle.

Thus the bottle contained 2038.5 cubic inches; the temperature of the air of the bottle was 59° of Fahrenheit; the altitude of the mercury in the barometer was 29.07 inches. The temperature of the air, after two days, was 57.5° ; the altitude of the mercury in the barometer was 29.37 inches; the caustic alkali of the bottle weighed 5 lbs. $9\frac{1}{2}$ oz., equal to 131.2713 cubic inches. But, on account of the ascent of the barometer, it is necessary to subtract 2.09 cubic inches, and 6.471 cubic inches, because the air in the bottle was rendered 1.5° (of Fahrenheit) colder: for as the volume of elastic fluids is in the inverse proportion of the weight pressing on them, $29.37 : 29.07 :: 2038.5 : x = 2017.6$: and $2038.5 - 2017.6 = 20.9$.

And as atmospheric air is expanded $\frac{1}{472.5}$ of it's volume for every degree of Fahrenheit's thermometer $\frac{2038.5}{472.5} \times 1.5^{\circ} = 6.471$. So $131.2713 - 20.9 - 6.471 = 103.9$, the number of cubic inches of fixed air in 2038.5 inches of air once respired; a quantity less than one nineteenth of the whole; for $\frac{2038.5}{103.9} = 19.6$. But, lest any part of the fixed air should be absorbed, oil was used instead of water.

The bottle was filled with air once respired and passed through oil: this bottle contained 179.812 cubic inches. Second experiment.

The thermometer and barometer were as in the last experiment. The caustic alkali, after two days, weighed $6\frac{1}{20}$ oz. and measured 11.451 cubic inches. But $29.37 : 29.07 :: 179.812 : x = 177.973$; and $179.812 - 177.973 = 1.839$; and $\frac{179.812}{472.5} \times 1.5^{\circ} = 0.5707$.

Thus $11.451 - 1.839 - 0.5707 = 9.042$, the quantity of

fixed air in 179.8 cubic inches of air once respired; for

$$\frac{179.812}{9.042} = 19.8.$$

The same experiment being repeated with the same bottle, 3 oz. 1 dr. only of caustic alkali, measuring 5.9148 cubic inches, were found in the bottle. But as during this time the mercury in the bottle had fallen six tenths of an inch, 3.817 cubic inches must be added to that quantity. And as the air in the bottle was found eight tenths of a degree colder towards the end than at the beginning of the experiment, 0.3044 parts of an inch are to be subtracted from it.

For $29.2 : 29.82 :: 179.812 : x = 183.629$; and $183.629 - 179.812 = 3.817$; and $\frac{179.8}{472.5} \times 0.8 = 0.3044$.

So that $5.9148 + 3.817 - 0.3044 = 9.427$. And $\frac{179.812}{9.427} = 19.07$.

In frequently repeating these experiments with the large and small bottles, whilst the state of the thermometer and barometer was carefully attended to, the greatest variation was 20.1 : so that the average number will be 19.6.

Dr. Menzies likewise made some experiments to discover the quantity of fixed air in the room where these were made; but the quantity in 2038.5 cubic inches of air respired was found to be so small as to be scarcely perceptible. If any calculation be attempted, the quantity of fixed air may be estimated at $\frac{1}{250}$ th or $\frac{5}{1250}$ dths of air once respired.

Thus, if the quantity of air commonly inspired be estimated at 40 cubic inches, and the number of respirations at 18 in a minute, 720 cubic inches will be inspired in the space of a minute; of which quantity only $\frac{27}{1250}$ dths, or 194.4 cubic inches consist of vital air, the only constituent of atmospheric air changed by respiration.

But, parts only of atmospheric air are changed in each respiration: hence 36 cubic inches of fixed air are generated in the space of a minute in the lungs of a middle-sized man, or 51840 cubic inches in the space of a day—a quantity of air weighing 22865.5 grs. or 3.9697 lbs. troy weight. And as Lavoisier has calculated that for every pound of fixed air generated by the combustion of coal a quantity of heat is evolved which would melt 27.02024 lbs. of ice; and as the same quantity of heat is generated in air vitiated either by respiration or by the combustion of coal; it follows that the quantity of air vitiated daily in the lungs of an ordinary man will give out nearly as much heat as would melt 107.2 lbs. of ice: for $27.02024 \times 3.9697 = 107.2622$. But as a portion of this heat is carried off in the air expired, under the form of sensible heat; and as a portion is employed in the formation of vapour, or is rendered latent; these quantities can be calculated in the following manner:—

As a cubic inch of atmospheric air weighs 0.32112 parts of a grain, 40 cubic inches will weigh 12.8448 grains. But $\frac{1}{128}$ parts of this quantity being converted into fixed air, if the whole remains free from moisture it will gain 0.19794: so that it will weigh 13.04274 grains. Hence the air expired during the space of a minute will weigh 234.7693 grains; or that expired during a whole day will weigh 338067.82 grains, or 58.692 pounds. But if air of this kind be supposed to have the same capacity for receiving heat as water, it follows that the same degree of heat that would raise 58.69 lbs. of water some degrees, would also raise the air to the same degree. But the quantity of heat requisite to raise 58.69 lbs. of water to the 66th degree of Fahrenheit, is equal to that which would melt 27.6692 lbs. of ice; for since 140 degrees of heat become latent in the formation of each pound of

water $\frac{58.69 \times 66^\circ}{140} = 27.6692$. Consequently the same degree of heat will be daily evolved in the lungs under the form of sensible heat.

The discovery of latent heat shows that a great quantity of heat is absorbed during the formation of vapour, without an increase of temperature; and, according to the experiments of Watt, the heat thus absorbed, or rendered latent, would raise the temperature of a body of the same specific gravity and capacity for heat as water, although it could not be converted into vapour, 960 degrees more than before.

Dr. Menzies weighed accurately a large allantoid, and then filled it with expired air. When it was quite cooled, and carefully weighed again, it was found to have gained two grains by every respiration; which coincides with an experiment made by Hales, who found that some moistened diaphragms, through which he had breathed, gained six grains in three minutes. Thus, if two grains of aqueous vapour be subtracted every minute, without attending to what may be subtracted for the difference between the weight of fixed and vital air, 6 oz. or 0.5 of a pound will be subtracted daily. But if the temperature of a body incapable of being evaporated, of the same capacity for heat as water, weighing 0.5, be increased 960 degrees, this heat will dissolve 3.42854 lbs. of ice: for $\frac{960 \times 0.5}{140} = 3.4285$. But as Crawford computes the relative heat of aqueous vapours at 1.55, a quantity of heat will be subtracted which would dissolve 1 lb. and 0.8856 hundredth parts of ice more than if its capacity for heat had been the same with that of water; or, in other words, all the heat daily consumed in the lungs, in forming aqueous vapour, would dissolve 5.3141 lbs. of ice. So that all the heat daily evolved in the lungs under the

form of sensible heat and vapour, would dissolve 32.9833 lbs. of ice. For $27.6692 + 5.3141 = 32.9833$.

But as it was before demonstrated, that in one day a quantity of heat was evolved by the change induced in the air in the lungs, which would dissolve 107.2622 lbs. of ice. Subtract thence 32.9833

There will remain 74.2789

which would be the quantity capable of being dissolved by the heat daily evolved in the lungs of an ordinary man. But it is necessary the blood should absorb the heat, because it is exposed to its action in the lungs for the space of some hundreds of square feet, and because this fluid is admirably calculated to diffuse heat through all the body.

The degree to which the blood is heated in its passage through the lungs, may, according to Dr. Menzies, be estimated in the following manner:—If the quantity of blood which passes through the lungs in the space of a minute may be estimated at 8 lb.; if the heart be supposed to propel an ounce and a half in each systole; and if the blood be supposed to have an equal capacity for heat with water; it is evident that the quantity of heat that would make 8 lbs. of water rise to any given point, would also make 8 lbs. of blood rise to the same point. But as the quantity of heat absorbed during a day by the blood has been shown to be sufficient to dissolve 74.27 lbs. of ice, the quantity absorbed each minute could only dissolve 0.05158 of a lb. of ice. Besides, since 140° of heat are requisite to liquefy 1 lb. of ice, or become latent, $1 : 140 :: 0.05158 : x = 7.22^{\circ}$, or the quantity of heat requisite for dissolving 0.05158 of a pound of ice would increase the temperature of a pound of water by 7.22° , or 8 lbs. by 0.90265 of a degree of the thermometer of Fahrenheit. Thus the heat generated each minute in the lungs of an ordinary man would raise the temperature of the blood passing

The degree to which the blood in the lungs is heated estimated.

through them in that space of time, by 0.90265 of a degree, if blood had an equal capacity for heat with water. But as Crawford concludes that the comparative heat of venous blood bears the same proportion to that of water as 0.8928 to 1, it is evident that the same degree of heat which would raise venous blood one degree would raise the same quantity of water only 0.8928 of a degree; or that their temperatures are in the inverse proportion of their capacities for heat.

Thus the quantity of heat would raise the same quantity of venous blood 1.01103° ; for $0.8928 : 1.0000 :: 0.90265 : \frac{0.90265 \times 1}{0.8928} = 1.01103$. And as he found that the capacity of venous blood for heat is increased by its becoming arterial, in the proportion of 0.8928 to 1.03; if venous blood is raised 1.01103° by the heat evolved in the lungs, it follows that arterial blood will be raised only 0.8763; for $1.03 : 0.8928 :: 1.01103 : x = 0.8763$.

Thus 0.13468 parts of a degree of Fahrenheit's thermometer equal the quantity of heat which becomes latent, although the capacity of the blood for heat is increased in the same proportion; for $1.01103 - 0.87635 = 0.13468$.

Therefore the blood in its passage through the lungs, according to the calculation of Dr. Menzies, gains 1.01103 , or more than one degree of Fahrenheit, and its temperature is increased 0.8763 of a degree. Whence it follows, that the blood in the left side of the heart is warmer than that in the right by eight tenths of a degree. This seems to be confirmed by an experiment of Hunter's on a live dog; for, having introduced the ball of a thermometer two inches within the rectum, the quicksilver rose to 100° and a half exactly. The chest of the dog was then opened, and a wound made in the left ventricle of the heart; and immediately on the ball being introduced the quicksilver rose to 101° exactly. A wound

was next made some way into the substance of the liver, and the quicksilver rose to 100° and three quarters. It was next put into the cavity of the stomach, where it stood at 101° . All these experiments were made in a few minutes.

Hence, according to Dr. Menzies, the quantity of animal heat generated in the lungs may be determined by a method founded on the two following propositions.

1. That nearly equal quantities of heat are evolved when equal quantities of vital air are vitiated, whether by the combustion of coal, or by the respiration of animals.

2. That the quantity of fixed air generated in the lungs in any given time, can be easily determined by knowing the quantity of fixed air in air once respired.

This method, therefore, has no connexion with any theory of animal heat, or with the different capacities of fixed and vital air for heat.

Different authors have given the heat of the human body. According to Boerhaave it's natural heat is 92° Heat of the human body. or at most 94° ; and Pitcairn makes the heat of the skin to be the same. It is however evident, that the different parts of the body not only differ from each other, but that they differ from themselves according to the seasons and other circumstances: hence the difference of the results amongst physicians who have attempted to ascertain the animal heat.

Amontons found it to be	91, 92, or 93°
Sir Isaac Newton	$95\frac{1}{2}$
Fahrenheit and Muschenbroek found the blood to be	96
Dr. Martine found the skin to be	97 or 98
————— the urine	99
Dr. Hales found the skin	97
————— the urine	103
John Hunter under his tongue	97
————— in his rectum	$98\frac{1}{2}$
————— in his urethra, at one inch	92

John Hunter in his urethra, at two inches	93°
_____ at four inches	94
_____ at the bulb of the urethra	97

Such are the phenomena respiration produces in the more perfect animals with warm blood; and such have been the various opinions with respect to the utility of this process, and the part it acts in the animal œconomy. The next part will give an account of the respiration of fishes and insects.

Experi-
ments of
Priestley.

Respiration of Fishes.—Dr. Priestley having found, according to the phlogistic system, that the principal use of the *lungs* and of the *blood* in man, quadrupeds, and animals with lungs, is to discharge phlogiston from the animal system, in a state proper to diminish respirable air, and to render it unfit for respiration, was desirous of trying whether fishes, which do not breathe like other animals, part with phlogiston to the water in which they live. With this view he put two (a large perch and an eel) into a pail of water; and when they had been in it about twenty-four hours he nearly filled a large phial with the water, and in it he agitated a small quantity of common air between six and seven minutes, and found that it was considerably injured by the operation; for two measures of this and one of nitrous air occupied at first the space of two measures and one sixth, and by standing several days were never less than two measures. But when he agitated an equal quantity of air in the same quantity of the same water in which no fishes had been confined, and for the same space of time, it was not injured in the slightest degree. It is evident, therefore, according to Priestley, that phlogiston is discharged from fishes as well as from other animals; that this phlogiston affects the water, and this water the air that is agitated in it; and in the same manner as the fishes themselves would have affected it, if it had been possible for them to breathe it. Other experiments

confirmed and extended these conclusions. Having filled a phial with some water from the hot well at Bristol, which he found to contain air in a great state of purity, he put a few minnows and other small fishes into it, about two inches in length, and confined them without any access of common air until they died. He then took equal quantities of the foul and of fresh water, and expelled from both all the air they would yield. That from the water in which no fishes had been put, or the fresh, exceeded the foul in the proportion of three to two; and by the test of nitrous air, the former exceeded the latter in a still greater proportion. The fresh was about the standard of common air, and the foul somewhat worse than air in which a candle just goes out: it might have been worse, but the water remained in an open vessel all night before the experiment. Hence, air contained in water in an unelastic state is as necessary to the life of fishes, as air in an elastic state is to that of land animals.

He then had no doubt but that putting fishes into water impregnated with air thoroughly phlogisticated would be equally injurious to them, as this air in an elastic state is to land animals; and this was verified. He began with rain water which contained no air, having been recently boiled. He put nine small fishes into a vessel containing about three pints of it, and they lived between three and four hours, no air having been admitted. Two fishes were put into a pint of it impregnated with phlogiston from air that had been phlogisticated six months before by means of iron filings and sulphur, and they lived in it nearly an hour. It was very imperfectly impregnated. Inflammable air had a similar effect. John Hunter having informed him that fishes would not live in water impregnated with fixed air, he tried it, and found that small fishes would not live in it more than a few minutes. It is well known that all spa waters containing fixed air are fatal to fishes, frogs, and

insects. He found that in water impregnated with nitrous air they were affected in the same manner, but more violently; but as a decomposition of some small part of the nitrous air might take place before he could possibly slip the funnel into the neck of the phial, he introduced the fishes into the vessel in which he had impregnated the water while it remained inverted in the basin, the remainder of the nitrous air not imbibed by the water still resting upon it. The phial contained something more than a pint, and the nitrous air occupied about one fourth of it. Into this vessel he introduced two small fishes, and they continued very quiet, without being seized with any convulsions (as happened before), ten minutes, or a quarter of an hour, before they died. Hence, the cause of the convulsions, in the former experiment, arose not from the *nitrous air*, properly speaking, but *nitrous acid*, which acted like the fixed air, another kind of acid. Whereas now the fishes were no otherwise affected than in water with phlogisticated or inflammable air, except that the water had imbibed more of the nitrous air, and hence was sooner fatal to them.

Broussonet. From the conformation of the organs of respiration, or the gills, in these animals, Broussonet has formed them into two divisions: *viz.* the cartilaginous, such as the sea-dog, the shark; and the spinous, as the sea-wolf, &c. In the first division, the gills are sustained by a cartilaginous arch, and are more considerable in number than in the second; in the last, they are supported by several small curved bones, the number being seldom less than four, and never exceeding it.

The structure of the gills is so formed, that the sanguinous vessels, which are distributed over them, make, as in the lungs of quadrupeds, a very long passage in a short space; but they differ very much in different kinds of fishes. The way of life to which nature has destined

these animals is the principal cause of these varieties, which rarely take place in the respiratory organs of different quadrupeds and birds. Thus fishes which live in still water and in places where the water is rarely renewed, such as eels, have their gills sustained by short osseous arches; the cavity of their gills is very large, and they are able to preserve the water in these organs a much longer time than other fishes. They may in some measure be compared to the reptiles and oviparous quadrupeds, which have cellular lungs furnished with fibres, and in such a manner as to be able to keep a certain quantity of air in reserve in case of need. On the contrary, in those species of fishes that frequent the high seas, and are destined to make long emigrations, and swim very rapidly, the gills are placed upon very great bones; several are provided with a peculiar organ, destined like the gills for respiration.

In animals that respire air there is only one aperture by which this element is received and rejected: this is not the case in fishes which receive water into their respiratory organs by different ways: thus, in the lamprey there is only one opening at the summit of the head, by which the water is conducted to the gills; in the ray there is one on each side of the head; whilst the greater number of fishes receive water by their mouth, and it departs by the gills. In the cartilaginous fishes, whose organs of respiration, as has been observed, are more extensive than those of other fishes, the greatest part reject the water by several openings; as in the lampreys, which have seven holes; the sea-dog has five, and the sturgeon has only one, forming several divisions. The other species of fishes have only one opening, but its form varies according to the animal economy of each kind. Thus, those destined to live in shallow waters and never at a distance from the banks, and sometimes buried in the sand, have this opening very small,

forming a species of canal surrounded by thick membranes. Those which are obliged to make rapid motions have their gills, on the contrary, the most extensively formed; their mouth and the opening of the gills are very large; they receive a great quantity of water, and renew it much oftener than the others; they die almost as soon as they are out of the water: whilst carp, eels, &c. which have small openings, live a long time in the open air. On comparing the respiration of fishes with that of animals that breathe in the open air, it appears, that the first more frequently inspire than the last; because the oxygen to be extracted from the water is much less abundant than in the atmosphere, and it is more difficultly separated from the water. Fishes, however, appear to have the advantage of a reservoir, which serves occasionally to supply the deficiency of oxygen by the respiratory organs. This is called the air-bladder of fishes. According to the experiments on the air which this bladder contains, by Brodbelt of Jamaica, particularly that of the sword-fish, it is pure oxygen gas: he thinks it serves the purposes of life when the animal is unable to come to the surface. Accum says the air-bladder of a carp contains common air. Monro had supposed it to contain fixed air. Fourcroy says it is azot gas united sometimes with a little carbonic acid gas; that it is produced in the stomach, and thence passes into this airy *receptacle*. Fishes are not able to support in water a degree of heat equal to that which man and quadrupeds support in the atmosphere, and the difference is very considerable. On making the comparison, physicians have observed, that air may be breathed by the human species at 264° with impunity. Tillet made animals breathe an air heated to 300° . A girl, likewise, under Marantin, breathed an air of 325° for five minute. Notwithstanding such degrees of heat would be insupportable to fishes, and would even be sufficient to

Air-bladder of fishes.

destroy their organization, several observations have been made on fishes found alive in very warm waters, and even by the ancients. Thus *Ælian* speaks of a lake in Libya, the water of which is very warm, and fishes are found in it which die if transported to a colder water. Similar observations are to be found in *St. Augustin* and *Cardanus*. *Shaw*, in his voyage to Barbary, speaks of several hot waters in which he had found several species of perch; and *des Fontaines* lately made the same observation in the neighbourhood of *Cafza*, where the thermometer of *R.* rose to 30° . *Lucas*, in his *History of Mineral Waters*, gives some observations on living carp found in a thermal water, the heat of which was equal to that of the human blood. *Valisnieri* and *Conringius* have likewise seen living fishes in thermal waters. *Anderfon* witnessed a similar fact in *Iceland*. But the most surprising fact is that of *Sonneret*, who found some fishes in a water at the *Manillas* at the degree of 69 of *Reaumur*. From the experiments of *Brouffonet*, fishes did not live at so high a temperature. *Muschenbroek* had already found that fishes perished at 111° of *Fahrenheit*; he even saw a very vigorous perch die in three minutes in a water heated to 96° . He adds, that these animals lived very well at 72° . It is very difficult to determine, in a positive manner, the different degrees of heat each species is able to bear; they differ not only according to the season, but likewise according to the forms of the organs of respiration.

On the 20th of June, 1784, *Brouffonet* put a couple of ten-spined stickle-backs (*epinoches*) into some water at a temperature of 14° . This was gradually heated, and at the end of two hours and a half the thermometer mounted to 28° : the fishes then became agitated, but on being cast into fresh water they became well again in a few minutes.

On the 10th of November, 1784, he put a carp, some bleaks, gudgeons, and perch, into some water of the *Seine*

at 5° , and the bottom of the vessel was covered with sand. At 25 minutes past twelve o'clock the thermometer was at $6\frac{1}{2}^{\circ}$; at 30 minutes at 8° , &c. This experiment lasted till 45 minutes past four; and he marked the degrees of heat every five minutes, pouring some fresh water into the vessel at different times in small quantities. At 12° , the smallest fishes began to rise to the surface of the water, became agitated and ill; yet the Seine water is much warmer in the summer. At 21° the small bleaks were nearly dead. At 22° the perch were motionless, and reversed. The gudgeons, which were of a larger size, did not appear to suffer till 23° ; whilst the carp was not at all agitated, its respiration being only more frequent. At 28° , at which point the water was kept 15 minutes, the carp began to lose its equilibrium, and became ill; it afterwards appeared dead, and only came to itself again after being left a long time in fresh water. Broussonet employed four hours and a half in bringing the heat of the water to 28° . He is of opinion that, with certain precautions, fish would live in a water heated beyond 28° .

“On supposing,” says Broussonet, “as I have reason to believe from my experiments, that fishes cannot support water heated beyond 30° ; on recollecting, at the same time, that it is impossible for them to live in a water the temperature of which is a few degrees below zero, it would follow that these animals could only live in a scale of 30 degrees at most; a scale which, when compared with that supported by warm-blooded animals, will appear very short: it will, however, always be in a ratio to the vital heat, which in fishes is even below that of reptiles and oviparous quadrupeds. Martine has observed of several salt-water fishes, that the heat of their blood did not exceed the water in which they were. more than one degree. The same experiment re-

“ repeated upon a trout, and other river-fish, afforded him
“ the same result. Mr. John Hunter saw the thermome-
“ ter in the stomach of a carp rise from $65\frac{1}{2}^{\circ}$, which was
“ the temperature of the water, to 69° , i. e. three degrees
“ and a half higher : but it is necessary to observe that
“ the fish was then out of the water ; which must have a
“ great influence on the result of the experiment.”

Broussonet plunged a thermometer into the bodies of several small fishes of the Seine, which never rose higher than three fourths of a degree beyond the temperature of the water ; sometimes it only increased half a degree, particularly in those that were ill. A pretty large eel, although weak, only caused the thermometer to rise three fourths of a degree. Carp constantly gave one degree more, some a degree and a half ; so that it appears the animal heat of fishes is very inconsiderable.

According to the same author, fishes are subject to a great loss of animal heat by the water continually extracting it ; so that the portion of this fluid immediately surrounding them is warmer than elsewhere. It has been observed, that a carp plunged into a mixture that soon became congealed, preserved around it a certain quantity of fluid water, although the rest was totally congealed.

The animal heat of fishes, no doubt, arises from their respiration ; for the phenomena by which Lavoisier and de la Place have explained it's production in animals living in the atmosphere, are observed also in fishes, but in a less evident degree : the difference of heat between animals breathing air, and those which respire water, is more particularly remarkable on comparing fishes with the cetaceous order. Both inhabit the same element ; yet those with gills, that respire water, have only one degree or one and a half more than the water itself, whilst the cetaceous order that respire air have their blood as warm as man. Broussonet found the body of a porpoise

just dead to be $28\frac{1}{2}^{\circ}$ in the neck, whilst the temperature of the atmosphere was at 14° , and that of the sea-water near the shore at $13\frac{1}{2}^{\circ}$.

It also appears that fishes do not suffer such extreme variations of cold and heat as quadrupeds. The temperature of the water, at a certain depth, is almost always the same, as appears, with respect to the sea, from the experiments of Marfili and Saussure. That of rivers, when the surface is frozen, is a few degrees above zero in the middle. In great heats, the temperature of the water is always below that of the air.* Yet it appears that these animals are more sensible to a great degree of heat than of cold.

Fishes are, however, affected by the variations of the atmosphere; and it is to its great variations in temperature that the emigration of that prodigious quantity of herrings is to be attributed, which the cold of the pole forces annually to seek more temperate seas. Fishes likewise which live near the banks, feel the cold of the air, and go into deeper places to protect them from it, where the greater part remain in a state of torpidity, similar to what bears, marmots, and dormice undergo during the winter. The ancients have given some account of this periodical sleep, whilst the moderns have scarcely observed it. The fishes of this order may be, however, known by the great length of their body, the absence of the ventral fins, and the undulating motions they are obliged to make to support themselves in the water.

It is observed that water affects the organs of respiration in fishes, in a greater variety of ways than air acts upon those of warm-blooded animals. Several individuals, after having respired a certain quantity of water for some time, vitiate it so much as to be no longer proper for respiration, in the same manner as warm-blooded animals change the air. Water, likewise, holds in solution a

greater number of substances than the air; and amongst these many are found to be prejudicial to fishes, by acting on their respiratory organs, which more rarely happens to animals living in the atmosphere. They are able, however, to resist some of these changes: thus, they pass from salt to sweet waters, and reciprocally, without detriment; numbers of salmon, shads, lampreys, &c. annually leave the sea and mount the fresh water rivers, whilst the carp often quits the river for the saltness of the ocean. Brouffonet found that fishes are able to live in distilled water; that they at first showed signs of uneasiness, but after swimming about for some time they no longer appeared to suffer; he thinks it most probable, that by moving about they had caused the water to unite with a quantity of air sufficient for respiration. He, however, found that a small fish enclosed in a corked bottle containing a pint of distilled water, lived more than thirty hours. He found that a small quantity of sirup of violets, dropped into the distilled water in which were living fishes, at first underwent no change of colour: it became somewhat green afterwards, arising perhaps from the alkali of the mucus with which they are covered, and which always mixes with the water. A drop of acid of arsenic in a large quantity of water immediately killed a very strong fish. Water slightly impregnated with fixed air destroyed a similar fish in a few minutes. Plunged into lime water they likewise very soon died. It was well known that by throwing lime into water fishermen are accustomed to destroy the fishes; and by several other substances the same is effected. Thus, in the Indies the juices of several species of plants are made use of. In the south of France the milky juice of the *euphorbia characias* of Linnæus, which grows there in great abundance in uncultivated places, is employed for the same purpose. It is by affecting the

respiratory organs of these animals that their death is occasioned.

Bell.

We are informed by Bell (in contradiction to what Broussonet has said), that if there be no air in the water in which fishes are, or not in sufficient quantity for them to breathe, they die; that distilled water is to these animals what the vacuum of an air-pump is to an animal that respire air in the atmosphere; that if you exhaust water of it's air by a pump, or boil or distil it, or by any other means deprive it of it's air, fishes are no longer able to breathe in it; that they rise to the surface and gasp for air; and that on extracting the air from water in which fishes have respired, it is found to be contaminated exactly in the same manner as air respired by warm-blooded animals; and that it differs very little from that in which a candle has spontaneously become extinguished; which, according to this author, are sufficient facts to prove that the gills of these animals perform the same functions of a real respiration as the lungs of a man and quadrupeds, which extract the oxygen from the atmosphere.

Davy.

For more satisfactory information respecting the respiration of fishes, we are indebted to Davy; for, as it has been supposed that fishes decompose both water and oxygen gas, he made the following experiments to ascertain the truth.

1st Experiment. He expelled, by long boiling, the atmospheric air from 64 cubic inches of sea-water: he then excluded it from the air by means of mercury. Having then introduced a small mullet, it was instantly convulsed, and died in a few minutes.

2d Experiment. A quantity of water was freed, by boiling, of it's atmospheric air: two receivers, each of the capacity of 36 cubic inches, were filled with this water: into one of these two cubic inches of nitrogen

were introduced, into the other two of phos-oxygen. By long and constant agitation the gases were dissolved by the water, which was excluded from the contact of air by mercury. Into each of the receivers two minnows were introduced. Those in the water holding nitrogen in solution died in about four minutes, those in the water holding phos-oxygen, in solution appeared totally uninjured, and when examined, after some hours, were still alive and healthy.

3d Experiment. The same receivers used in the last experiment were filled with distilled water freed from atmospheric air by a second boiling. Into each of these, three cubic inches of phos-oxygen were introduced. The receivers were then agitated for some time, till the water in each of them had dissolved an equal quantity of gas; they were then inverted in a trough of mercury, so as to exclude atmospheric air from them. Four minnows were then conveyed into one of them through mercury. The receivers were now suffered to remain untouched for six hours, when they were examined. The minnows were alive, and no gas remained in the top of the receiver in which they had respired. The gas in the top of the other receiver remained nearly the same as at the commencement of the experiment. A quantity of lime-water was poured into each of these receivers; in that in which the fishes had existed there was a very perceptible cloudiness, occasioned, as Davy supposed, by the formation of carbonat of lime; in the other there was no perceptible change.

From these experiments Davy concludes, that the venous blood in the gills of fishes is phos-oxydated by the phos-oxygen held in solution by water; and that carbonic acid, and probably water, are given out as excrementitious by the venous blood in their gills. With respect to the decomposition of water by fishes in respiration, as there is

no evidence of hydrogen being formed, there can be no reason for the supposition.

Respiration of Insects.—From the much greater length of time insects are capable of existing than other animals in carbonic acid gas, and, according to Dr. Priestley, in air infected by putrid effluvia, it had been supposed by some physiologists that this class of animals either had the power of living a certain time without breathing, or that they had not the same occasion for it as others whose respiration is well understood. It had not been considered, that as insects, from their habits of life, are accustomed to live in places where the air is in a state of great impurity, they would not be so liable to experience its bad effects, as those who constantly breathe a purer atmosphere: nor was it well understood by what means this function was carried on in this most numerous part of the animal kingdom.

Scheele and
Bergman.

It was, indeed, a fact acknowledged by Scheele and Bergman, that insects, the same as other animals, converted vital air into mephitic gas by the act of respiration; but no experiments of any consequence had taken place on this subject before those of Vanquelin, at least they were by no means so satisfactory. It is now well known that the function of respiration is not performed by the mouth of insects, by which they differ very much from warm-blooded animals, and that they have not like them a pulmonary organ into which the blood passes to receive the influence of the air from the atmosphere.

It is now well understood, that insects take in this element by means of certain openings or holes, to which entomologists have given the name of stigmata, from their resemblance to so many spots on the surface of their body. These stigmata are of various forms; sometimes they are round, sometimes oval, but in general they are lengthened

like a button-hole. With respect to the number, it varies according to the nature and size of the animal.

The experiments of Vauquelin were made on the grass-hopper (*gryllus viridiflms*), the red slug (*limax flavus*), and the snail (*helix pomalia* of Linnæus). The grass-hopper has 24 stigmata disposed in four rows, parallel and exterior to the two white lines placed longitudinally on the middle of it's belly, and the motions of inspiration and expiration are well marked. Vauquelin found that this animal died immediately on being put into sulphureous hydrogenous gas. In six cubic inches of pure air it existed 18 hours, and in eight of common air 36 hours: he found that oxygen gas was indispensably necessary to the life of this insect; that as soon as there no longer remains any or very little of this gas in the atmospheric air, it immediately dies. The atmospheric air in which several had died was found to contain scarcely any remnant of oxygen gas: but whatever number were suffered to breathe until their complete asphyxy, it was not observed that they had entirely converted the vital air into carbonic acid; they appeared constantly to die before this conversion was complete. He attributes this to the sensibility of the animal for the carbonic acid gas, which destroys it when in large proportion as well as azot gas.

The respiratory organs of the red slug have not as yet been discovered by anatomists; but Vauquelin looks upon them to be the lateral openings of this animal, which are seen to dilate and contract. This slug, on being put into 12 cubic inches of atmospherical air, died in 48 hours; and not the least appearance of oxygen gas was found afterwards, the remaining air precipitating lime water; which proves that it was entirely converted into fixed air. This chemist was much astonished to find how completely this animal had analysed the atmospherical air, having never discovered the least trace of vital air in the residuum

of that respired, when examined by means of phosphorus. "Hence," says he, "it appears that worms have in their respiratory organs a great power of separating the oxygen gas from the particles of azot gas with which it is on all sides surrounded, and that they have no occasion for a large quantity of oxygen at one time; that they are able to remain for some time without respiring in the ordinary way; and, thirdly, that they are not very sensible to the influence of carbonic acid gas formed in the respired atmospherical air, and of the azot gas left naked." A slug consumed in 48 hours 3.36 inches of oxygen gas, when it immediately rolled itself up, emitting from all parts a milky liquor, and died.

In sulphureous hydrogenous gas a slug showed no signs of life in about half an hour; which proves that worms cannot exist in an elastic fluid containing no oxygen gas, although of all animals they appear from their manners of life to have the least occasion for it.

With respect to the last animal, the *snail*, it lived four days in 12 cubic inches of atmospherical air. The oxygen of this air was found to be entirely absorbed, or deprived of its natural principle; for the azot gas remaining did not contain an atom of it, the residuum likewise contained carbonic acid. That the death of this animal was owing to the want of oxygen, and not to the want of food, he proved by finding that others of the same species were able to live several months without any food.

From these experiments it appears,

1st. That insects and worms respire oxygen gas like warm blooded animals, and that like them they convert it into water and carbonic acid.

2d. That this principle is absolutely necessary in their respiration, and that they die when deprived of it.

3d. That every other elastic fluid, except oxygen gas, is unfit for their respiration.

4th. That worms, and particularly the red slug and the esculent snail, appear to have very extraordinary respiratory powers, and very little sensibility for the presence of carbonic acid, since they separate all the vital air from the azot gas, and from the carbonic acid which is formed; and that they only perish when there no longer remains any oxygen gas.

5th. That this property, Vauquelin thinks, may render these last animals very useful as an eudiometer, by offering a proper means of exactly separating the oxygen gas from the azot gas, and consequently of affording a perfect knowledge of the proportions of the principles of the atmospherical air, or of a vital air, the degree of purity of which may be required.

Davy has discovered, by experiments similar to those Davy made upon fishes, that the zoophytes have their respiration governed by similar laws; that they, like fishes, absorb the phos-oxygen held in solution by water, as well as portions of nitrogen; and thus, in their chemical attractions as well as in their organic powers, they seem to form the connecting links between animals and vegetables.

There now remains to give an account of the experiments and conclusions of this last author on the nitrous oxyd, and some other gases, which he made upon himself and various animals, forming a curious mass of information.

This ingenious experimentalist begins by explaining the word *respirable*; which term he employs to denote those gases capable of being taken into the lungs by voluntary efforts. On the contrary, *nonrespirable* gases, when applied to the external organs of respiration, stimulate the muscles of the epiglottis in such a way, as to keep it perfectly close on the glottis, which prevents the smallest

particle of gas from entering into the bronchia, in spite of voluntary exertions. One only has the power of uniformly supporting life—atmospheric air. Other gases, when respired, sooner or later produce death, but in different modes. Some, as nitrogen and hydrogen, effect no positive change in the venous blood. Animals immersed in these gases die of a disease produced by privation of atmospheric air, analogous to that occasioned by their submersion in water or nonrespirable gases. Others, as the different varieties of hydrocarbonat, destroy life by producing some positive change in the blood, which probably immediately renders it incapable of supplying the nervous and muscular fibres with principles essential to sensibility and irritability. Oxygen, which is capable of being respired for a much greater length of time than any other gas, except common air, finally destroy life; first producing changes in the blood, connected with new living action.

In making his experiments, Davy made use of a large mercurial air-holder, the invention of Clayfield: in it's form it is analogous to Watt's hydraulic bellows, consisting of a glass bell playing under the pressure of the atmosphere, in a space between two cylinders filled with mercury. The instrument was graduated to the cubic inch of Everard, and furnished with a stop-cock.

To ascertain the changes effected by respiration, the stop-cock having a very large orifice, curved and flattened at it's upper extremity, formed an air-tight mouth-piece. By accurately closing the nose, and bringing the lips tight on this mouth-piece, after a few trials, he was able to breathe oxygen or common air for two minutes or two minutes and a half, without any other uneasy feeling than that produced by the inclination of the neck and chest towards the cylinder: but the power of uniformly exhausting the lungs and fauces to the same extent, required a

longer time. At last, by preserving exactly the same posture, after exhaustion of the lungs before the inspiration of the gas to be experimented upon, and during it's complete expiration, he found he could always retain nearly the same quantity of gas in the bronchial vessels and fauces, the difference in the volume expired at different times never amounting to a cubic inch and half.

By connecting the conducting pipe of the air holder, during the respiration of the gas, with a small trough of mercury by means of a curved tube, it became a perfect and excellent breathing machine: for, by exerting a certain pressure on the air holding cylinder, it was easy to throw a quantity of gas, after every inspiration or expiration, into tubes filled with mercury standing in the trough. In these tubes it could be accurately analysed, and thus the changes taking place at different periods of the process ascertained.

Davy was first induced to the examination of this gas, Nitrous oxyd. or the dephlogisticated nitrous gas of Dr. Priestley, from Mitchill's Theory of Contagion, which is looked upon by the experimentalist as fallacious. In 1799 he began the investigation: but a considerable time elapsed before he was able to procure the gas in a state of purity, and his first experiments were made on the mixtures of nitrous oxyd, nitrogen, and nitrous gas, which are produced during metallic solutions. Dr. Mitchill attempted to prove that this gas, which he calls oxyd of septon, is the principle of contagion (*vide* art. Miasmata), and capable of producing the most terrible effects when respired by animals in the minutest quantities, or even when applied to the skin or muscular fibre. Davy, however, on making a few coarse experiments on small quantities of the gas procured from zinc and diluted nitrous acid, found that wounds were exposed to it's action, and the bodies of animals immersed in it, without injury; and that he was

able to breathe it, but with remarkable effects. He often breathed a quart of it, or even two quarts, mingled with more than equal parts of oxygen or common air. In the most decisive of these trials, it's effects appeared to be depressing, and he imagined it produced a tendency to fainting; the pulse was rendered slower under it's operation. He then inspired the pure gas; and as it passed through the bronchia without stimulating the glottis, and produced no uneasy feeling in the lungs, it proved the nitrous oxyd to be respirable.

Method of
procuring
it.

The pure nitrous oxyd was procured by the decomposition of nitrat of ammonia, in a temperature not exceeding 440° . 200 grains of compact nitrat of ammonia were introduced into a glass retort, and decomposed slowly by the heat of a spirit lamp. The first portions were rejected, and the last received in jars containing mercury. This gas, when collected, exhibited the following properties;

It's properties.

a. A candle burnt in it with a brilliant flame and crackling noise. Before it's extinction, the white inner flame became surrounded with an exterior blue one.

b. Phosphorus introduced into it in a state of inflammation burnt with infinitely greater vividness than before.

c. Sulphur introduced into it when burning with a feeble blue flame, was instantly extinguished; but when in a state of active inflammation (i. e. forming sulphuric acid) it burnt with a beautiful and vivid rose coloured flame.

d. Inflamed charcoal deprived of hydrogen introduced into it, burnt with much greater vividness than in the atmosphere.

e. Iron burned with great vividness, and threw out bright sparks, as in oxygen.

f. Thirty measures of it exposed to water previously

boiled was rapidly absorbed: when the diminution was complete, rather more than a measure remained.

g. Pure water saturated with it gave it out again on ebullition, and the gas thus produced retained all its former properties.

h. It was absorbed by red cabbage juice, but no alteration of colour took place.

i. Its taste was distinctly sweet, and its odour slight, but agreeable.

j. It underwent no diminution when mingled with oxygen or nitrous gas.

After the absorption of the nitrous oxyd by water, there remained another gas; on examining which it appeared reasonable to conclude,

1st. That the residual gas of nitrous oxyd is air previously contained in the water (which in no case can be perfectly freed from it by ebullition), and liberated by the stronger attraction of that fluid for nitrous oxyd.

2d. That nitrat of ammonia at temperatures below 440° is decomposed into pure nitrous oxyd and fluid.

3d. That in ascertaining the purity of nitrous oxyd from its absorption by water, corrections ought to be made for the quantity of gas expelled from the water; this quantity in common water distilled under mercury being about $\frac{1}{3}$ th; in water simply boiled and used when hot about $\frac{1}{4}$ th, and in common spring water $\frac{1}{2}$ th.

It's specific gravity; accounting for the small quantity of common air contained in it (90 cubic inches of it containing about $\frac{1}{3}$ th of common air, introduced from the mercurial air holder into an exhausted globe, which increased it in weight 44.75 grains, the thermometer being 50° and atmospheric pressure 30.7); was concluded to be such, that 100 cubic inches weigh 50.1 grains at temperature 50° , and at atmospheric pressure 37. It's specific gravity.

Composition.

Respired
by warm-
blooded
animals.

It is composed of oxygen and nitrogen; for, drawing conclusions from the quantity of carbonic acid formed, 2.5 grains of nitrous oxyd are composed of .82 oxygen, and 1.68 nitrogen; or 100 grains of nitrous oxyd contain 37 of oxygen, and 63 of nitrogen. On making experiments on the respiration of nitrous oxyd by warm blooded animals, it was procured as above related, and received in large jars filled with water previously saturated with the gas. The animal was introduced into the jar by being carried under the water, by which it suffers little or nothing: after it's introduction, the jar was made to rest on a shelf about half an inch below the surface of the water, and the animal carefully supported so as to prevent it's mouth from resting in the water. The animals experimented upon were the cat, dog, rabbit, guinea pig, mouse, and goldfinch.

In each of these experiments a certain absorption of the gas was always perceived, the water rising in the jar during the respiration of the animal. From these it appears,

It's effects.

1st. That nitrous oxyd is destructive, when respired for a certain time, to the warm blooded animals, apparently previously exciting them to a great extent.

2d. That when it's operation is stopped before complete exhaustion is brought on, the healthy living action is capable of being gradually reproduced, by enabling the animal to respire atmospheric air.

3d. Exhaustion and death are produced in the small animals by nitrous oxyd sooner than in the larger ones, and in young animals of the same species, in a shorter time than in old ones.

He found that animals live at least twice as long in nitrous oxyd as they do in hydrogen or water; consequently, there was every reason to suppose from this circumstance

alone, that their death in nitrous oxyd could not depend on the simple privation of atmospheric air: but that it was owing to some peculiar changes effected in the blood by the gas.

The external appearance of animals that have been de-^{On dissec-}stroyed in nitrous oxyd is very little different from that of those killed by privation of atmospheric air. The fauces and tongue appear of a dark red, and the eyes are dull and a little protruded. Their internal organs, however, exhibit a very peculiar change: the lungs are a pale brown red, and covered here and there with purple spots; the liver is of a very bright red, and the muscular fibre in general dark. Both the auricles and ventricles of the heart are filled with blood. The auricles contract for minutes after the death of the animal. The blood in the left ventricle and the aorta is of a tinge between purple and red, whilst that in the right ventricle is of a dark colour, rather more purple than the venous blood. These appearances are similar to those observed by Dr. Beddoes in animals that had been made to breathe oxygen a great length of time.

From other experiments on the respiration of mixtures of nitrous oxyd and other gases, and on recapitulating those before mentioned, it appears,

1. That warm blooded animals die in nitrous oxyd in-^{Recapitula-}initely sooner than in common air or oxygen; but not nearly in so short a time as in gases incapable of effecting positive changes in the venous blood, or in nonrespirable gases.
2. The larger animals live longer in nitrous oxyd than the smaller ones, and young animals die in it sooner than old ones of the same species.
3. When animals, after breathing nitrous oxyd, are removed from it before complete exhaustion has taken

place, they are capable of being restored to health under the action of atmospheric air.

4. Peculiar changes are effected in the organs of animals by the respiration of nitrous oxyd. In animals destroyed by it, the arterial blood is purple red, the lungs are covered with purple spots, both the hollow and compact muscles are *apparently* very irritable, and the brain is dark coloured.

5. Animals are destroyed by the respiration of mixtures of nitrous oxyd and hydrogen, nearly in the same time as by pure nitrous oxyd: they are capable of living for a great length of time in nitrous oxyd, mingled with very minute quantities of oxygen or common air.

Amphibious animals.

As it appeared that the nitrous oxyd destroyed warm blooded animals, by increasing the living action of their organs to such an extent as finally to exhaust their irritability and sensibility; it was reasonable to conjecture that the cold blooded animals, possessed of voluntary power over respiration, would so regulate the quantity of nitrous oxyd applied to the blood in their lungs, as to bear it's action for a great length of time. But this conjecture, on experiment, was found to be erroneous.

From the experiments upon them, it appears that water lizards, and most probably the other amphibious animals, die in nitrous oxyd in a much shorter time than in hydrogen, or pure water; consequently, their death in it cannot depend on the simple privation of atmospheric air.

Fishes.

It was expected that fishes, like amphibious animals, would have been very quickly destroyed by the action of nitrous oxyd; but although water saturated with nitrous oxyd had no positive effects upon them, they ought, according to Davy, to die in it much sooner than in water deprived of air by ebullition. From their living in it rather longer, it may be concluded, that they are de-

stroyed not by privation of atmospheric air, but from some positive change effected in their blood by the gas.

He had long ago observed, that the gills of fishes became rather of a lighter red during their death in the atmosphere, and conjectured that the disease of which they died was probably hyperoxygenation of the blood connected with highly increased animal heat. For not only is oxygen presented to their blood in much larger quantities in atmospheric air than in its aqueous solution, but likewise in a state in which it contains, to use common language, much more *latent heat*. Without, however, laying any stress on this supposition, he had the curiosity to try whether thornbacks would live longest in atmospheric air or nitrous oxyd. In one experiment they appeared to die in them nearly in the same time. In another, the fish in nitrous oxyd lived nearly half as long again as that in atmospheric air. The winged insects furnished with breathing holes became motionless in nitrous oxyd very speedily: being, however, possessed of a certain voluntary power over respiration, they sometimes recover, after having been exposed to it for some minutes, under the action of atmospheric air. A butterfly died in nitrous oxyd in six minutes; in hydrogen, in five minutes. A large fly became motionless in nitrous oxyd in half a minute; in hydrogen, in a quarter of a minute; in hydro-carbonat it dropped immediately senseless. Flies live much longer under water, alcohol, or oil, than in non-respirable gases, or gases incapable of supporting life. A certain quantity of air always continues attached in the fluid to the fine hairs surrounding their breathing holes, sufficient to support life for a short time.

Snails and earth worms live in nitrous oxyd a long while; they die in it, however, much sooner than in water or hydrogen, probably from the same causes as amphibious animals.

Insects.

Snails and
earth
worms.

Having discovered that the nitrous oxyd was respirable, the next thing was to investigate the changes effected in it by the venous blood; and finding that the residual gas of nitrous oxyd, after it had been breathed for some time in silk bags, was chiefly nitrogen, the conjecture at first was, that the nitrous oxyd was decomposed in respiration in the same manner as atmospheric air, and it's oxygen only combined with the venous blood: but experiments proved the contrary; for it was found,

It's effects
on venous
blood.

1st. That when nitrous oxyd is agitated in fluid venous blood, a certain portion of the gas is absorbed, whilst the colour of the blood changes from dark red to red purple.

2d. That during the absorption of nitrous oxyd by the venous blood, minute portions of nitrogen and carbonic acid are produced, either by evolution from the blood, or from a decomposition of part of the nitrous oxyd.

3d. That venous blood impregnated with nitrous oxyd is capable of oxygenation; and, *vice versa*, that oxygenated blood may be combined with nitrous oxyd.

Changes in
the nitrous
oxyd by
respiration.

To ascertain accurately the changes effected in nitrous oxyd by respiration, a large mercurial air holder of the capacity of 200 cubic inches was used. Whenever the pure nitrous oxyd was breathed after a complete voluntary exhaustion of the lungs, the pleasurable delirium was rapidly produced; and being obliged to stoop on the cylinder, the determination of blood to the head from the increased arterial action in less than a minute became so great, as often to deprive the experimentalist of voluntary power over the muscles of the mouth. Hence he could never rely on the accuracy of any experiment in which the gas had been respired for more than three fourths of a minute. He was able to respire the gas with great accuracy for more than half a minute; and in all his experiments on the respiration of this nitrous oxyd, a very considerable diminution of gas always took place, and the

diminution was in general apparently greater to the eye during the first four or five inspirations.

The residual gas of an experiment was always examined as follows: After being transferred through mercury into a graduated cylinder, a small quantity of concentrated solution of caustic potash was introduced into it, where it remained in contact some hours: the diminution was then noted, and the quantity of gas absorbed by the potash judged to be carbonic acid. To the remainder twice it's bulk of pure water was admitted; and, after agitation and rest for four or five hours the absorption was noticed, and the gas absorbed considered as nitrous oxyd. The residual unabsoorbable gas was mingled over water with twice it's bulk of nitrous gas; and by these means it's composition, whether it consisted wholly of nitrogen, or of nitrogen mingled with small quantities of oxygen, ascertained.

From a number of experiments, the following are selected as the most accurate on the respiration of nitrous oxyd:

1. At temperature 54° , 102 inches of nitrous oxyd were breathed, which contained nearly $\frac{1}{3}$ th common air, for about half a minute, seven inspirations and seven expirations being made. After every expiration an evident diminution of gas was perceived; and on the last full expiration it filled a space equal to 62 cubic inches.

These 62, being analysed, were found to consist of

Carbonic acid	.....	3.2
Nitrous oxyd	.....	29.0
Oxygen	.....	4.1
Nitrogen	.....	25.7

62.0

Hence, accounting for the two cubic inches of common

air previously mingled with the nitrous oxyd, 71 cubic inches had disappeared.

2. At temperature 47° , 182 were breathed, with $2\frac{1}{2}$ of atmospheric air of the air holder, for 40 seconds—in all eight respirations. The gas after the last expiration equalled 128 cubic inches, which, on analysis, consisted of

Carbonic acid	.....	5.25
Nitrous oxyd	.....	88.75
Oxygen	.....	5.00
Nitrogen	.....	29.00

Consequently 93.25 cubic inches had disappeared in this experiment. Hence nitrous oxyd is rapidly absorbed by the venous blood through the moist coats of the pulmonary veins. But as, after a complete voluntary exhaustion of the lungs, much residual air must remain in the bronchial vessels and fauces, as appears from their incapability of completely collapsing, it is evident that the gas expired after every inspiration of nitrous oxyd must be mingled with different quantities of the residual gas of the lungs; and after a complete expiration, much of the unabsorbed nitrous oxyd must remain as residual gas in the lungs. Now, when a complete expiration is made after the breathing of atmospheric air, it is evident that the residual gas of the lungs consists of nitrogen mingled with small portions of oxygen and carbonic acid, because these products are formed during the respiration of common air, and they are the only products found after the respiration of nitrous oxyd.

To ascertain whether these products were partly produced during the process of respiration, or whether they were wholly the residual gases of the lungs, was found extremely difficult. The first, however, is the most probable.

For this purpose the author first thought of breathing nitrous oxyd immediately after his lungs had been filled

with oxygen, and to compare the products remaining after the full expiration with those produced after a full expiration of pure oxygen; but this idea was relinquished. He attempted to inspire nitrous oxyd, after having made two inspirations, and a complete expiration of hydrogen; but the effects of the hydrogen were so debilitating, and the consequent stimulation by the nitrous oxyd so great, as to deprive him of sense.

Though experiments on successive inspirations of pure nitrous oxyd might go so far as to determine whether or no any nitrogen, carbonic acid, and oxygen were products of respiration; yet he distinctly saw that it was impossible in this way to ascertain their quantities, supposing them produced, unless he could first determine the capacity of his lungs, and the different proportions of the gases remaining in the bronchial vessels after a complete expiration, when atmospheric air had been respired. In some experiments (made on the respiration of hydrogen, to determine whether carbonic acid was *produced* by the combination of carbon loosely combined in the venous blood with the oxygen respired, or whether it was simply *given out* as excrementitious by this blood) he found, without being able to resolve the problem, that in the respiration of pure hydrogen, little or no alteration of volume took place; and that the residual gas was mingled with some nitrogen, and a little oxygen and carbonic acid.

From the comparison of these facts with those on the absorption of nitrous oxyd by venous blood, and on the effects produced upon animals by the respiration of nitrous oxyd, there was every reason to suppose that hydrogen was not absorbed or altered, when respired, but only mingled with the residual gases of the lungs.

Hence, by making a full expiration of atmospheric air, and afterwards taking six or seven respirations of hydrogen in the mercurial air-holder, and then making

To ascertain the capacity of the fauces and bronchia, and the composition of the gas remaining in them.

a complete expiration, he thought that the residual gas and the hydrogen would be so mingled, as that nearly the same proportions should remain in the bronchial vessels as in the air-holder. By ascertaining these proportions, and calculating from them, he hoped to be able to ascertain with tolerable exactness the capacity of his fauces and bronchia, as well as the composition of the gas remaining in them, after a complete expiration of common air.

Hydrogen.—The hydrogen employed for this purpose was procured from the decomposition of water by means of clean iron filings and diluted sulphuric and muriatic acids. It was breathed in the same manner as nitrous oxyd, in the large mercurial air-holder. The difficulty of making the experiments was great, from the difficulty of breathing hydrogen for half a minute so as to make a complete expiration of it, after a complete voluntary exhaustion of the lungs. The purity of the hydrogen was ascertained immediately before the experiment by the test of nitrous gas, and by detonation with oxygen in atmospheric air: generally 12 measures of atmospheric air were fired with four of the hydrogen; and if the diminution was to ten or a little more, the gas was judged pure. After the experiment, when the complete expiration had been made, and the common temperature restored, the volume of the gas was noticed, and then a small quantity of it thrown into the mercurial apparatus, by means of the conducting tube, to be examined. The carbonic acid was separated by solution of potash or strontian; the quantity of oxygen ascertained by nitrous gas of known composition; the superabundant nitrous gas was absorbed by a solution of muriat of iron; and the proportions of hydrogen and nitrogen in the remaining gas discovered by inflammation with atmospheric air or oxygen in the detonating tube by the electric spark.

The two following experiments on quantities of hydrogen, equal to those of the nitrous oxyd, respired in the foregoing experiments, are the most accurate of five.

Exp. 1. He respired at 59°, 102 cubic inches of hydrogen, apparently pure, for rather less than half a minute, making seven quick respirations. After the complete expiration, when the common temperature was restored, the gas occupied a space equal to 103 cubic inches nearly. These analysed were found to consist of

Carbonic acid	.....	4.0
Oxygen	.....	3.7
Nitrogen	.....	17.3
Hydrogen	.....	78.0

.103.0

Now, as in this experiment the gas was increased in bulk only a cubic inch; supposing that after the complete expiration the gas in the lungs, bronchia, and fauces, was of nearly similar composition with that in the air-holder, and that no hydrogen had been absorbed by the blood, it would follow that 24 cubic inches of hydrogen remained in the internal organs of respiration, and consequently, by the rule of proportion, about 7.8 of the mixed residual gas of the common air. And then the whole quantity of residual gas of the lungs, supposing the temperature 59°, would have been 31.8 cubic inches; but as it's temperature was nearly that of the internal parts of the body, 98°, it must have filled a greater space; calculating from the experiments of Guyton and Vernois (*An. de Ch. t. i. p. 979*) about 37.5 cubic inches.

From the increase of volume, it would appear that a minute quantity of gas had been generated during the respiration; and this was most probably carbonic acid: for

there is no reason to suppose the production of nitrogen. There is also reason to suppose that a little of the residual oxygen must have been absorbed. Making allowances for these circumstances, it would follow that the 37.5 cubic inches of gas remaining in the lungs of the operator, after a complete expiration of atmospheric air, animal heat 98° , equal to 31.3 cubic inches at 59° , were composed of

Nitrogen	24.9
Carbonic acid	4.9
Oxygen	5.0
	<hr/>
	31.8
	<hr/>

Exp. 2. He respired for near a minute and a half in the mercurial air-holder at 61° , 182 cubic inches of hydrogen, making six long inspirations. After the last expiration, the gas filled a space nearly equal to 184 cubic inches, and analysed was found to consist of

Carbonic acid	4.8
Oxygen	4.6
Nitrogen	21.0
Hydrogen	153.6
	<hr/>
	184.0
	<hr/>

Now in this experiment, reasoning as before, 28.4 cubic inches of hydrogen must have remained in the lungs, and likewise 5.5 of the atmospheric residual gas. Consequently, the whole residual gas was nearly equal to 34 cubic inches at 61° , which at 98° would become about 40.4 cubic inches. And it would appear also, that the quantity of gas remaining in the lungs, after a complete voluntary respiration, equalled at 98° , about 40 cubic inches, and at 61° , 34 nearly; that after common air had been breathed, the 34 cubic inches consisted of

Carbonic acid	.....	4.1
Oxygen	.....	5.5
Nitrogen	.....	24.4
		<hr/>
		34.0
		<hr/>

It would have been possible, according to the operator, to prove the truth of the postulate on which the experiments were founded, by respiring common air or oxygen after the complete expiration of the hydrogen, for the same time as the hydrogen was respired, and in equal quantities. For, if portions of hydrogen were found in the air-holder equal to those of the residual gases in the two experiments, it would prove that a *uniform* mixture of residual gas, with the gas inspired, was produced by the respiration. This mixture, however, appeared so evident from analogous facts as to make the proofs unnecessary.

Indeed, as most gases, though of different specific gravities, when brought into contact with each other, assume some sort of union, it is more than probable that gas inspired into the lungs, from being placed in contact with the residual gas on such an extensive surface, must instantly mingle with it. Hence, possibly one deep inspiration and complete expiration of the whole of a quantity of hydrogen of the lungs after complete voluntary exhaustion, will be sufficient to determine the capacity and the nature of the residual air.

That two inspirations are sufficient, appears probable from the following

Exp. 3. After a complete voluntary expiration of common air, he made two deep inspirations of 141 cubic inches of hydrogen. After the complete expiration, they filled a space equal to rather more than 142 cubic inches, and analysed were found to consist of

LIFE.

Carbonic acid	.....	3.1
Oxygen	.....	4.5
Nitrogen	.....	18.8
Hydrogen	.....	115.6
		<hr/>
		142.0
		<hr/>

Calculating from this experiment on the exhausted capacity of the lungs, supposing uniform mixture, they would contain, after expiration of common air, about 30.7 cubic inches at 58°, equal to 36 at 98°, composed of about

Nitrogen	.....	20.9
Oxygen	.....	5.8
Carbonic acid	.....	4.0
		<hr/>
		30.7
		<hr/>

It might be supposed, *a priori*, that in this experiment much less of the residual oxygen of the lungs must have been absorbed, than in experiments 1 and 2; yet there is no very marked difference in the portions evolved. That a tolerably accurate mixture took place, appears from the quantity of nitrogen. The smaller quantity of carbonic acid is an evidence in favour of it's evolution from the venous blood.

It is reasonable to suppose that the pressure upon the residual gas of the exhausted lungs must be nearly equal to that of the atmosphere; but as aqueous vapour is perpetually given out by the exhalents, and perhaps evolved from the moist coats of the pulmonary vessels, it is likely that the residual gas is not only fully saturated with moisture at 98°, but likewise impregnated with uncombined vapour, and hence it's volume enlarged beyond the

increment of expansion of temperature. Considering all these circumstances, and calculating from the mean of the three experiments on the composition of the residual gas, Davy concludes—

1st. That the exhausted capacity of his lungs was equal to about 41 cubic inches.

2d. That the gas contained in the bronchial vessels and fauces, after a complete expiration of atmospheric air, was equal to about 32 cubic inches—it's temperature being reduced to 55°.

3d. That these 32 cubic inches were composed of about

Nitrogen,	23.0
Carbonic acid,	4.1
Oxygen,	4.9
	<hr/>
	32.0
	<hr/>

In many experiments made in the mercurial air-holder, on the capacity of the lungs under different circumstances, he found that he threw out of his lungs, by a full forced expiration, at temperature from 58° to 62°,

Cubic Inches.

After a full voluntary inspiration, from 189 to 191

After a natural inspiration, from78 to 79

After a natural expiration, from67 to 68

So that, making the corrections for temperature, it would appear that his lungs in a state of voluntary inspiration contained about 254 cubic inches; in a state of natural inspiration about 135; in a state of natural expiration about 118; and in a state of forced expiration 41. But as the exhausted capacity, as well as impleated capacity, of the internal organs of respiration must be different in different individuals, according as the forms and size of their thorax, fauces, and bronchia are different, it would

be almost useless to endeavour to ascertain a standing capacity. It is, however, probable, that a ratio exists between the quantities of air inspired in the natural and forced inspiration, those expired in the natural and forced expiration, and the whole capacity of the lungs. If this ratio were ascertained, a single experiment on the natural inspiration and expiration of common air would enable us to ascertain the quantity of residual gas in the lungs of any individual after a complete forced expiration. The operator is of opinion that the capacity of his own lungs is below the medium—his chest being narrow, measuring in circumference only twenty-nine inches, and his neck rather long and slender.

Comments
on the ex-
periments
on the re-
spiration of
nitrous
oxyd.

Having thus ascertained the capacity of his lungs, and the composition of the residual gas of expiration, it remained to reason on the experiments on the respiration of nitrous oxyd.

In experiment I, nearly 100 cubic inches of nitrous oxyd (making the corrections on account of the common air) were respired for half a minute. In this time they were reduced to 62 cubic inches; which consisted of 3.2 carbonic acid, 29 nitrous oxyd, 4.1 oxygen, and 25.7 nitrogen.

But, as appears from the last section, there existed in the lungs, before the inspiration of the nitrous oxyd, about 32 cubic inches of gas, consisting of 23 nitrogen, 4.1 carbonic acid, and 4.9 oxygen—temperature being reduced to 59°. This gas must have been perfectly mingled with the nitrous oxyd during the experiment; and, consequently, the residual gas in the lungs, after the experiment, was of the same composition as that in the air-holder.

Supposing it, as before, to be about 32 cubic inches, from the rule of proportion they will be composed of

Nitrous oxyd,	14.7
Nitrogen,	13.3
Carbonic acid,	1.9
Oxygen,	2.1
	<hr/>
	32.0
	<hr/>

And the whole quantity of gas in the lungs and the air-holder, supposing the temperature 59° , will equal 94 cubic inches; which are composed of

Nitrous oxyd,	43.7
Nitrogen,	39.0
Carbonic acid,	5.2
Oxygen,	6.1
	<hr/>
	94.0
	<hr/>

But, before the experiment, the gas in the lungs and air-holder equalled 134 cubic inches; and these, reckoning for the common air, were composed of

Nitrous oxyd	100.0
Nitrogen,	24.3
Carbonic acid,	4.1
Oxygen,	5.6
	<hr/>
	134.0
	<hr/>

Hence it appears, that 56.3 cubic inches of nitrous oxyd were absorbed in this experiment, and 13.7 of nitrogen produced, either by evolution from the blood, or decomposition of the nitrous oxyd. The quantities of carbonic acid and oxygen approach so near to those existing after the respiration of hydrogen, that there is every reason to believe that no portion of them was produced in consequence of the absorption or decomposition of the nitrous oxyd.

In Experiment II, calculating in the same manner, before the first inspiration a quantity of gas, equal to 216.5 cubic inches at 47°, existed in the lungs and air-holder; and these 216.5 were composed of

Nitrous oxyd,	182.0
Nitrogen,	24.9
Carbonic acid,	4.1
Oxygen,	5.5
	<hr/>
	216.5
	<hr/>

After the complete expiration, 160 cubic inches remained in the lungs and air-holder; which were composed of

Nitrous oxyd,	110.6
Nitrogen,	36.3
Carbonic acid,	6.8
Oxygen,	6.3
	<hr/>
	160.0
	<hr/>

Hence it appears that 71.4 cubic inches of nitrous oxyd were absorbed in this experiment, and about 12 of nitrogen produced. The quantity of carbonic acid and oxygen is rather greater than that which existed in the experiments on hydrogen.

Nitrogen
produced
during re-
spiration
of nitrous
oxyd.

From these estimations he learned that a small quantity of nitrogen was produced during the absorption of nitrous oxyd in respiration. It remained to determine whether this nitrogen owed it's production to evolution from the blood, or to the decomposition of a portion of the nitrous oxyd.

Analogical evidences were not in favour of the hypothesis of decomposition. It was difficult to suppose that a body requiring the temperature of ignition for it's decomposition by the most inflammable bodies, should be partially absorbed and partially decomposed at 98° by a fluid apparently possessed of uniform attractions. It was more easy to believe that, from the immense quantity

of nitrogen taken into the blood in nitrous oxyd, the system soon became overcharged with this principle; which not being wholly expended in new combinations during living action, was liberated in the aeriform state by the exhalants, or through the moist coats of the veins. If the last rationale were true, it would follow that the quantity of nitrogen produced in respiration ought to be increased in proportion as a greater quantity of nitrous oxyd entered into combination with the blood.

To ascertain whether this was the case, he made, after full voluntary exhaustion of his lungs, one full voluntary inspiration and expiration of 108 cubic inches of nitrous oxyd. After this it filled a space nearly equal to 99 cubic inches; the quantities of carbonic acid and oxygen in these were not determined; but by the test of absorption by water, they appeared to contain only 18 nitrogen, which is very little more than should have been given from the residual gas of the lungs. In a second experiment he made two inspirations of 108 cubic inches of nitrous oxyd nearly pure: the diminution was to 95. On analysing these 95, he found, to his great surprise, they contained only 17 nitrogen. Hence he suspected some source of error in the process.

He now introduced into a strong new silk bag, the sides being in perfect contact, eight quarts of nitrous oxyd: it was mingled, from the mode of introduction, with a little common air, but not sufficient to disturb the results. He then adapted a cork cemented to a long curved tube to his right nostril; the tube communicated with the water apparatus; and the left nostril being accurately closed, and the mouth-piece of the silk bag lightly adapted to the lips, he made a full expiration of the common air of his lungs, inspired nitrous oxyd from the bag, and, by carefully closing the mouth-piece with his tongue, expired it through the curved tube into the water apparatus. In

this way he made nine respirations of nitrous oxyd. The expired gas of the first respiration was not preserved ; but part of the gas of the 2d, 3d, 5th, 7th, and 9th, were caught in separate graduated cylinders. The 2d, analysed by absorption, consisted of about 29 absorbable gas, which must have been chiefly nitrous oxyd ; and 17 unabsorbable gas, which must have been chiefly nitrogen ; and the 3d of 22 absorbable gas and eight unabsorbable. The fifth was composed of 27 to 6 ; the 7th of 23 to 7 ; and the 9th of 26 to 11.

Though the results of these experiments were not so conclusive as could be wished ; yet, comparing them with those of the experiments on the changes effected in nitrous oxyd by respiration, it seemed reasonable to conclude that the production of nitrogen was increased in proportion as the blood became more fully impregnated with nitrous oxyd.

From this conclusion, compared with the phenomena noticed on the absorption of nitrous oxyd by venous blood, and on the changes effected on the organisation of warm-blooded animals, by the respiration of nitrous oxyd, he is induced to believe that the production of nitrogen, during the respiration of nitrous oxyd, is not owing to the decomposition of part of the nitrous oxyd in the aëriform state *immediately* by the attraction of the red particles of venous blood for it's oxygen ; but that it is rather owing to a new arrangement produced in the principles of the impregnated blood during circulation ; from which, becoming supersaturated with nitrogen, it gives it out through the moist coats of the vessels.

Production
of nitrogen
from the
new ar-
rangement
in the prin-
ciples of the
impregna-
ted blood.

For if any portion of nitrous oxyd were decomposed immediately by the red particles of the blood, the quantity of nitrogen produced ought to be greater during the first inspirations, before these particles became fully combined with condensed oxygen. If, on the contrary, the

whole of the nitrogen and oxygen of the nitrous oxyd were both combined with the blood and carried through the pulmonary veins and left chamber of the heart to the arteries, then, supposing the oxygen chiefly expended in living action, whilst the nitrogen was only partially consumed in new combinations, it would follow that the venous blood of animals made to breathe nitrous oxyd, hyperfaturated with nitrogen, must be different from common venous blood; and there is reason to believe this from the phenomena, on the changes effected in the organisation of warm-blooded animals by the respiration of nitrous oxyd.

Besides nitrogen, carbonic acid and water have been noticed to be the products of the respiration of nitrous oxyd.

Of the other products, carbonic acid and water.

As nearly equal quantities of carbonic acid are produced, whether hydrogen or nitrous oxyd is respired, provided the process is carried on for the same time, there is every reason to believe that no part of the carbonic acid produced is generated from the immediate decomposition of nitrous oxyd by carbon existing in the blood: hence it must be either evolved from the venous blood, or formed by the slow combination of the oxygen of the residual air of respiration with the charcoal of the blood.

But if it was produced from the decomposition of residual atmospheric air, it would follow that it's volume must be much less than that of the oxygen of the residual air which had disappeared; for some of this oxygen must have been *absorbed* by the blood, and during the conversion of oxygen into carbonic acid by charcoal a slight diminution of volume is produced.

In the experiments when nitrous oxyd and hydrogen were respired for half a minute, the medium quantity of carbonic acid produced was 5.6 cubic inches.

- Suppose the quantity of carbonic acid produced is in

the ratio of the oxygen diminished, and there is every reason to believe that, in the expiration of atmospheric air, the expired air and the residual air are nearly of the same composition. Hence no more carbonic acid can remain in the lungs, or be produced from the residual gas, after the complete expiration of common air, than that which can be generated from a volume of atmospheric air equal to the residual gas of the lungs. This residual gas, after complete expiration, equals at 55° , 32 cubic inches, and 32 cubic inches of common air contain 8.6 cubic inches of oxygen. But in the experiments on the respiration of hydrogen, not only 5.6 cubic inches of carbonic acid were produced, but more than four of residual oxygen remained unabSORbed.

The carbonic acid evolved through the coats of the vessels.

Hence it appears impossible that all the carbonic acid could have been produced by the combination of charcoal in the venous blood with residual atmospheric oxygen; there is therefore every reason to believe, that it is wholly or partially liberated from the venous blood through the moist coats of the vessels. The water carried out of the lungs in solution, by the expired gas of nitrous oxyd, could neither have been wholly nor partially formed by the decomposition of nitrous oxyd. The coats of the vessels in the lungs, and indeed in the whole internal surface of the body, are always covered with moisture; and the solution of part of this moisture by the inspired heated gas, and its deposition by the expired gas, are, according to Davy, sufficient causes for the appearance of the phenomenon. There are no reasons for supposing that any of the residual atmospheric oxygen is immediately combined with fixed or nascent hydrogen, or hydrocarbonat, in the venous blood, at 98° , by slow combustion, and consequently none for supposing that water is immediately formed in respiration. The evolution of water from the vessels in the lungs is almost certain from nu-

The water evolved from the

merous analogies. He found that nitrous oxyd can be respired without danger by man for a much longer time than that required for the death of the smaller quadrupeds in it. He has breathed it two or three times in a considerable state of purity for four minutes and a quarter; and four minutes and a half, and some diseased individuals for five minutes. Three quarts, *i. e.* about one hundred and seventy-four cubic inches, are consumed so as to be unfit for respiration by a healthy individual with lungs of moderate capacity in about one minute and a quarter; six quarts, or 348 cubic inches, last generally for two minutes and half or two minutes and three quarters; eight quarts, or 464 cubic inches, for more than three minutes and half; and 12 quarts, or 696 cubic inches, for nearly five. He is inclined to believe that nitrous oxyd is absorbed more rapidly after heavy meals, or during stimulation from wine or spirits, than at other times; and as it's absorption appears to depend on a simple solution in the venous blood, probably diminution of temperature will increase it's capability of being absorbed. The range of the consumption of different individuals does not extend to more than a pint, or 30 cubic inches, at the maximum dose; hence the medium of consumption is not far from two cubic inches, or about a grain every second, or 120 cubic inches, or 60 grains, in a minute. When nitrous oxyd is breathed in tight silk bags, towards the end of the experiment, as the internal surface becomes moist, a certain quantity of common air penetrates through; but it is too small to destroy any of the effects of the nitrous oxyd.

vessels in
the lungs.

Having thus ascertained the absorption of nitrous oxyd in respiration, and the evolution of nitrogen and carbonic acid from the lungs, during it's absorption, he was anxious to compare the changes effected in this gas, with those produced in nitrous oxyd and oxygen; considering

On the respiration of atmospheric air.

atmospheric air as a compound, in which principles identical with those in nitrous oxyd existed, though in different quantities and looser combination.

The composition of the atmospheric air before inspiration, and after expiration, was ascertained in the following manner: 40 measures of it were agitated over mercury in solution of caustic potash, and here it remained two or three hours in contact. The diminution was noted, and the gas absorbed judged to be carbonic acid. Twenty measures of the gas, freed from carbonic acid, were mingled with 30 of nitrous gas, in a tube of five inches diameter; they were *not agitated*, but suffered to rest an hour or an hour and half, when the volume occupied by them was noticed; and $50-m$ the volume occupied, divided by three, considered as the oxygen x , and $20-x$ considered as the nitrogen. When they are *agitated* a greater proportion of nitrous gas is absorbed and condensed in the nitric acid by the water; and to find the oxygen $x = \frac{50-m}{3.4}$ or $\frac{50-m}{3.5}$

Exp. 1. To ascertain the changes effected in atmospheric air by single inspirations, he made after a complete voluntary exhaustion of his lungs, at temperature 61° , one inspiration and expiration of 141 cubic inches of this air. After expiration they filled a space equal to 139 cubic inches. These analysed were found to consist of

Nitrogen	101
Oxygen	32
Carbonic acid . .	6

The 141 cubic inches before respiration were composed of 103 nitrogen, 1 carbonic acid, and 37 oxygen. The time taken to perform the inspiration and full expiration was a quarter of a minute. He repeated this experiment seven or eight times, and the quantity of oxygen absorbed was generally from five to six cubic inches;

the carbonic acid formed from five to 5.5, and the quantity of nitrogen apparently diminished from one to three cubic inches.

Exp. 2. After a voluntary expiration of common air, he made one inspiration and full expiration of 100 cubic inches of atmospheric air. It was diminished nearly to $98\frac{3}{4}$ or 99 cubic inches, and, analysed, was found to consist of

Nitrogen	.....	71.7
Oxygen	.....	22.5
Carbonic acid	.....	4.5

This was repeated four or five times with little difference of result, and there always seemed to be a small diminution of nitrogen. He found he took into his lungs at every natural inspiration 13 cubic inches of air, and threw out at every expiration rather less, or about $12\frac{3}{4}$ cubic inches.

The mean composition of the 13 cubic inches of air inspired was

Nitrogen	.....	9.5 cubic inches
Oxygen	.....	3.4
Carbonic acid	...	0.1

That of the 12.7 of air expired

Nitrogen	.....	9.3 cubic inches
Oxygen	.....	2.2
Carbonic acid	....	1.2

These results he gained from more than 20 experiments, which show their accuracy. He made about 26 or 27 natural inspirations a minute. So that, calculating from the above estimations, it follows, that 31.6 cubic inches of oxygen were consumed, and 5.2 cubic inches of nitrogen lost in respiration every minute, whilst 26.6 cubic inches of carbonic acid were produced.

To collect the products of a great number of natural expirations, so as to ascertain whether their composition

corresponded with the above accounts, he fastened his lips tight on the mouthpiece of the exhausted airholder, and, suffering his nostrils to remain open, inspired naturally through them, throwing the expired air through his mouth into the airholder.

In many experiments, he found that in about half a minute he made in this way 14 or 15 expirations. The mean quantity of air collected was 171 cubic inches, and consisted of

Nitrogen	.....	128	cubic inches
Oxygen.	.....	29	
Carbonic acid	....	14	

On comparing these results with the former ones, the mean quantities of air respired in equal times are rather less; but the proportions of carbonic acid, nitrogen, and oxygen, in the respired air, nearly identical.

To ascertain the changes effected in a given quantity of atmospheric air by continued respirations, he breathed, after a complete expiration, at temperature 63° , 161 cubic inches of air for near a minute, making 19 deep inspirations. After the complete expiration, the gas filled a space nearly equal to 152 cubic inches, so that nine cubic inches of gas had disappeared.

The 152 cubic inches, analysed, were found to consist of

Nitrogen	.....	111.6	cubic inches
Oxygen,	.....	23.	
Carbonic acid	....	17.4	

The 161 cubic inches before inspiration were composed of

Nitrogen	.....	117.0	cubic inches
Oxygen	.....	42.4	
Carbonic acid	....	1.6	

But the residual gas in the lungs, before the experiment, was of different composition from that remaining in the lungs after the experiment. It appears, therefore, after

making proper corrections, that about 5.1 of nitrogen were absorbed in respiration, 23.9 of oxygen consumed, and 12 of carbonic acid produced. This experiment was repeated three times with similar results, and the residual gas of similar composition. So that, supposing the existence of no source of error in the experiments, from which the quantity and composition of the residual gas of the lungs were estimated, the absorption of nitrogen as Priestley had suspected, by venous blood, appears demonstrated. To compare the changes effected in atmospheric air by respiration of the smaller quadrupeds with the above, he introduced into a 20-cubic-inch jar, filled with mercury in the mercurial trough, 15 cubic inches of atmospheric air, deprived of it's carbonic acid by long exposure to solution of potash. Temperature being 64° , a healthy small mouse was quickly passed under the mercury into the jar. He continued nearly 49 minutes without apparently suffering, at 20 minutes he lay on his side, and in 55 minutes was apparently dying, but exposed to the warmth of a fire recovered. The gas in the jar filled a space nearly equal to 14 cubic inches; so that a diminution of a cubic inch had taken place. These 14 cubic inches, analysed, consisted of

Carbonic acid 2.0 cubic inches

Oxygen 1.4

Nitrogen 10.6

The 15 cubic inches before the experiment consisted of

Oxygen 4 cubic inches

Nitrogen 11

Hence 2.6 cubic inches of oxygen had been consumed, two cubic inches of carbonic acid produced, and about 0.4 of nitrogen lost. The relation, therefore, between the quantities of oxygen consumed, and carbonic acid produced, are nearly the same as those in the former experiments; but the quantity of nitrogen lost is much smaller.

Respiration
of oxygen.

The gases before and after respiration were analysed in these experiments as in the last, except that three of nitrous gas were always employed to one of oxygen.

Exp. 1. At temperature 53° , after a full forced expiration, he respired in the mercurial airholder, for half a minute, 102 cubic inches of oxygen, making seven long and deep inspirations. After the complete expiration, the gases filled a space equal to 93 cubic inches: these 93, analysed, consisted of

Carbonic acid 5.9 cubic inches

Nitrogen 33.8

Oxygen 53.3

The 102 cubic inches before the experiment were composed of

Oxygen 78 cubic inches

Nitrogen 24

The residual gas in the lungs, before the experiment, was 32 cubic inches, and composed of 23 nitrogen, 4.1 carbonic acid, and 4.9 oxygen. The residual gas, after expiration, of 18.2 oxygen, two carbonic acid, and 11.8 nitrogen.

Hence the whole of the gas in the lungs and airholder before inspiration was 134 cubic inches, composed of

Oxygen 82.9 cubic inches

Nitrogen 47.0

Carbonic acid . . . 4.1

and after respiration, 125 cubic inches, consisting of

Oxygen 71.5 cubic inches

Nitrogen 45.6

Carbonic acid . . . 7.9

so that, comparing the quantities, it appears that 11.4 of oxygen, and 1.4 of nitrogen, were consumed in this experiment, and 3.8 of carbonic acid produced. He was surprised at the small quantity of oxygen consumed, being less than that during the respiration of atmospheric air.

for half a minute: the portion of carbonic acid evolved was smaller.

Exp. 2. He respired at the same temperature, after a full expiration, 162 cubic inches of gas, composed of 133 oxygen, and 29 nitrogen, for two minutes. After the experiment they were equal to 123 cubic inches. On analysis it appeared, that 57 cubic inches of oxygen, and two of nitrogen, had been absorbed; whilst 21 cubic inches of carbonic acid had been formed. It appears, therefore, from the estimations in the last section, that 63 cubic inches of oxygen are consumed, and about 52 cubic inches of carbonic acid produced, every two minutes, during the natural respiration of common air. So that six cubic inches less of oxygen are absorbed, and 30 cubic inches less of carbonic acid produced, every minute, when oxygen nearly pure is respired than when atmospheric air is respired.

Comparative consumption of atmospheric air and oxygen.

To ascertain the comparative consumption of atmospheric air and oxygen, by the smaller quadrupeds, he procured two healthy mice.

Exp. 3. One was introduced into a jar, containing $10\frac{1}{2}$ cubic inches of oxygen, and three cubic inches of nitrogen, and made to rest on a bit of cheese. The other was introduced into a jar containing $15\frac{1}{2}$ cubic inches of atmospheric air. In the first it suffered in half an hour, and was dying in one hour. The jars were often agitated, that the gases might be well mingled. The mouse in the atmospheric air was feeble in 40 minutes, and in 50 unable to stand.

The gas in the oxygen jar filled a space equal to 12.7 cubic inches, and, analysed, consisted of 1.7 carbonic acid, 2.6 nitrogen, and 8.4 of oxygen. So that 2.1 cubic inches of oxygen had been consumed, and 0.4 of nitrogen, and 1.7 of carbonic acid produced.

The gas in the atmospheric jar was diminished nearly

to 14.4, and consisted of 2.1 carbonic acid, 1.4 oxygen, and 10.9 nitrogen. So that 2.7 of oxygen, and five of nitrogen had been consumed, and 2.1 of carbonic acid produced.

It appears therefore that the mouse in atmospheric air consumed nearly one third more oxygen, and produced nearly a quarter more carbonic acid in 55 minutes than the other in an hour and a quarter in oxygen.

On the
changes ef-
fected in
the blood
by atmo-
spheric air
and oxygen.

From the experiments of Cigna and Priestley, the coagulum of the venous blood becomes florid at it's surface when exposed to the atmosphere, though covered and defended from the immediate contact of the air by a very dark stratum of serum. Hence serum is capable of dissolving either the whole compound atmospheric air, or it's oxygen. Supposing it dissolves the whole, it follows, that the colouring of the coagulum of blood under serum depended on the decomposition of the atmospheric air condensed in the serum; it's oxygen combining with the red particles and the nitrogen, either remaining dissolved in the fluid, or being liberated through it into the atmosphere; for the circulating blood consists of red particles, floating in and diffused through serum and coagulable lymph. In natural respiration, the red particles are rendered of a brighter tinge during the passage of the blood through the pulmonary veins: and, as before seen, during respiration, atmospheric air is decomposed, all the oxygen of it consumed, *apparently* a small proportion of the nitrogen lost, and a considerable quantity of carbonic acid produced.

Most probably, the whole compound atmospheric air, passing through the moist coats of the vessels, is first dissolved by the serum of the venous blood, and in it's condensed state decomposed by the affinity of the red particles for it's oxygen, the greater part of the nitrogen being liberated unaltered, but a minute portion of it possibly re-

maining condensed in the serum and coagulable lymph, and passing with them into the left chamber of the heart.

From the experiments on the respiration of nitrous oxyd and hydrogen, it appears that a certain portion of the carbonic acid produced is evolved from the venous blood ; but, as a much greater quantity is generated during the respiration of common air and oxygen than during that of hydrogen in equal times, it is not impossible but that some portion of it may be formed by the combination of charcoal in the red particles with the oxygen dissolved in the serum.

Supposing that no part of the water evolved in solution by the expired gas of common air is formed immediately in respiration, it will follow that a very considerable quantity of oxygen must be constantly *combined* with the red particles, even allowing the consumption of a certain portion of it to form carbonic acid ; for the carbonic acid evolved rarely amounts to more than three-fourths of the volume of the oxygen consumed. Perhaps the serum is capable of dissolving a larger quantity of atmospheric air than of pure oxygen.

It therefore appears that nitrous oxyd, when respired by animals, produces peculiar changes in their blood and in their organs, first connected with increased living action, but terminating in death ; that it is rapidly absorbed by the circulating venous blood, and of course it's condensed oxygen and nitrogen distributed in the blood over the whole of the system.

He could breathe nine quarts of nitrous oxyd for three minutes, and twelve for rather more than four, but could never breathe it in any quantity so large as five. When it's operation was carried to the highest extent, the pleasurable thrilling about it's height about the middle of the experiment gradually diminished, the sense of pressure on

Observations on the respiration of nitrous oxyd.

the muscles was lost, impressions ceased to be perceived, voluntary power destroyed, and the mouthpiece generally dropped from his unclosed lips.

He made some experiments to ascertain the analogy that existed between the sensible effects of the different gases, which are sooner or later fatal to life when respired, and those of nitrous oxyd.

Hydrogen. Pure hydrogen had been often respired by different philosophers, particularly by Scheele, Fontana, and Rofier. Davy respired four quarts of it, nearly pure, produced from zinc and muriatic acid, for near a minute; his lungs being previously exhausted, and his nostrils carefully closed. The first six or seven inspirations produced no sensations whatever; in half a minute his chest was oppressed, which gradually increased until the pain of suffocation obliged him to leave off. He felt no giddiness, his pulse was feebler and quicker, and his cheeks at last became purple. When the hydrogen was procured from iron and diluted vitriolic acid, he was unable to respire three-fourths of a minute; giddiness and debility were produced, the pulse feeble, and the suffocation greater than before.

Nitrogen. He breathed three quarts of nitrogen, mingled with a very small portion of carbonic acid, for near a minute. It produced no alteration for twenty seconds; then the sense of suffocation gradually came on, and increased rapidly the last quarter of the minute, so as to compel him to desist. The pulse was feebler and quicker. The head not affected.

Hydr-carbonat. Watt's observations on the respiration of diluted hydro-carbonat by men, and Dr. Beddoes' experiments on animals by pure hydro-carbonat, proved it's effects to be highly deleterious. Davy breathed for near a minute three quarts of it mingled with nearly two quarts of atmospheric air, which had never been breathed so little

diluted before. It produced a slight giddiness and pain in the head, and a momentary loss of voluntary power. He then resolved to breathe pure hydro-carbonat: for this purpose, he introduced into a silk bag four quarts of gas, nearly pure, produced from the decomposition of water by charcoal an hour before, and which had a strong and disagreeable smell. After a forced exhaustion of the lungs, and the nose being accurately closed, he made three inspirations and expirations. The first produced a sort of numbness and loss of feeling in the chest, and about the pectoral muscles. After the second inspiration he lost all power of perceiving external things, and had no distinct sensation, except a terrible oppression on the chest. During the third expiration this feeling disappeared, and he seemed sinking into annihilation, and had just power enough to drop the mouth-piece from his unclosed lips. He was very ill and feeble after. He thinks it proves that hydro-carbonat acts as a sedative; *i. e.* it produces diminution of vital action and debility, without previously exciting. He thinks four or five inspirations instead of three would have destroyed life immediately, without producing any painful sensation.

He attempted to respire carbonic acid, not being then acquainted with the experiments of Rosier: he introduced into a silk bag four quarts of well washed carbonic acid, produced from carbonat of ammonia by heat (which is in a high state of purity, and readily effected), and after a complete voluntary exhaustion of his lungs attempted to inspire it. It produced a sense of burning at the top of the uvula. It was in vain to make voluntary efforts to inhale it; at the moment the epiglottis was raised a little, a painful stimulation was induced, so as to close it spasmodically on the glottis. Thus, after repeated trials, he was prevented from taking a single particle of carbonic acid into the lungs.

He tried to breathe a mixture of two quarts of common air and three of carbonic acid, without success, it being nonrespirable. He found a mixture of three quarts of carbonic acid with seven of common air to be respirable, and breathed it for near a minute. It produced a slight giddiness and inclination to sleep. They however rapidly disappeared after ceasing to respire it. Carbonic acid possesses no action on arterial blood: hence perhaps it's slight effects when breathed, mixed with large quantities of common air. It's effects are very marked upon venous blood.

Oxygen.

The oxygen was procured from manganese by heat. In respiring eight or ten quarts, for the first two or three minutes, he perceived no effect. Towards the end his respiration became oppressed, and he felt a sensation as if he wanted fresh air, though but little of the oxygen had been consumed. In one experiment, when he breathed from and into a bag containing twenty quarts of oxygen for near six minutes, his pulse was not altered in velocity, but rather harder than before. He perceived no effects but those of oppression on the chest. Watt had suspected that the effects attributed to oxygen produced from manganese by heat, in some measure depended upon nitrous acid, suspended in the gas formed during ignition by the union of the oxygen of the manganese, with nitrogen likewise condensed in it; and in the course of his experiments on nitrous acid, Davy several times experienced a severe oppression on the chest and difficulty of respiration, not unanalogous to that produced by oxygen, but more violent; which seems to confirm Watt's suspicion.

Nitrous gas.

Being resolved to endeavour to breathe the nitrous gas, he introduced 114 cubic inches of it into a large mercurial airholder: two small silk bags of the capacity of seven quarts were filled with nitrous oxyd. After a forced exhaustion of his lungs, his nose accurately closed, he

made three inspirations and expirations of nitrous oxyd in one of the bags, to free his lungs as much as possible from atmospheric oxygen; then after a full expiration of the nitrous oxyd, he transferred his mouth from the mouthpiece of the bag to that of the airholder, and turning the stop-cock, attempted to inspire the nitrous gas. In passing through his mouth and fauces it tasted astringent and highly disagreeable, caused a sense of burning in the throat, and a spasm of the epiglottis so painful as to oblige him immediately to desist. After moving his lips from the mouthpiece which he opened to inspire common air, æriform nitrous acid was instantly formed in his mouth, which burnt the tongue and palate, and inflamed the mucous membrane. He never intends again to attempt so rash an experiment.

He frequently respired nitrous oxyd mingled with different proportions of common air or oxygen, and the effects produced by the diluted gas were much less violent than those produced by pure nitrous oxyd. They were generally pleasant, the thrilling was not often perceived, but a sense of exhilaration was almost constant.

Most extensive action of nitrous oxyd produces no debility.

Immediately after a journey of 126 miles, being much exhausted from having had no sleep the preceding night, he respired seven quarts of nitrous oxyd for near three minutes. It produced the usual pleasurable effects. He continued exhilarated for some minutes afterwards, and in half an hour found himself neither more or less exhausted than before the experiment: he had a great propensity to sleep. He repeated the experiment four or five times the following week with the same effect. He had experienced no decisive exhaustion after the excitement, although he was still far from being satisfied it was unanalogous to stimulants in general.

It occurred to him, that, supposing nitrous oxyd to be a stimulant of the common class, the debility produced in consequence of excessive stimulation by a known agent,

ought to be *increased* after excitement from nitrous oxyd.

He therefore drank a bottle of wine in large draughts in less than eight minutes (being accustomed to drink only water), which intoxicated him. Having remained in a state of insensibility for two hours and a half, he awakened with head-ach and painful nausea. His bodily and mental debility was excessive, and his pulse feeble and quick. He then respired twelve quarts of oxygen for nearly four minutes; and he supposed he was somewhat exhilarated. The head-ach and debility still continuing with violence, he respired seven quarts of pure nitrous oxyd for two minutes and a half. He was unconscious of head-ach after the third inspiration, and was exceedingly exhilarated. The next morning he was well. This proves that debility from intoxication was not increased by excitement from nitrous oxyd.

To ascertain with certainty whether the most extensive action of nitrous oxyd compatible with life was capable of producing debility, he resolved to breathe the gas for such a time and in such quantities as to produce excitement equal in duration, and superior in intensity, to that occasioned by high intoxication from opium or alcohol. To habituate himself to the excitement, and carry it on gradually, he was enclosed in an air-tight breathing box of the capacity of $9\frac{1}{2}$ feet. Taking a situation in which he could, by means of a curved thermometer inserted under the arm, and a stop watch, ascertain his pulse and animal heat, twenty parts of nitrous oxyd were thrown into the box; the smell and taste were immediately evident. In four minutes he felt a slight glow in the cheeks and a diffused warmth over the chest, though the temperature of the box was not quite 50° ; his pulse was 104 and hard, the animal heat 98° . In ten minutes the animal heat was near 99° ; in a quarter of an hour 99.5° , and the pulse 102, and fuller than

before. Twenty quarts more were now thrown into the box, and well mingled by agitation. In twenty five minutes the animal heat was 100° , pulse 124. In thirty minutes twenty quarts more were introduced : his sensations were exhilaration, a generally diffused warmth, and a disposition to muscular motion and merriment. In three quarters of an hour the pulse was 104, animal heat not 99.5° , the temperature of the chamber was 64 , the pleasurable feelings increased, the pulse fuller and lower ; and in about one hour it was 88, and the animal heat 99° . Twenty quarts more were admitted. He had now a great disposition to laugh, luminous points passed before the eyes, his hearing more acute, and a pleasant lightness and power of exertion were felt in his muscles. The symptoms then became stationary, respiration rather oppressed, and from the great desire of action rest was painful. He now came out of the box, having been in precisely one hour and a quarter.

He immediately began to respire twenty quarts of pure nitrous oxyd ; a thrilling extending from the chest to the extremities was almost immediately produced ; his pleasurable sensations increased, he lost all connexion with external things, and he existed in a world of newly connected and newly modified ideas. When awakened from this semidelicious trance by the bag being taken from his mouth, indignation and pride were his first feelings at sight of those around him ; his emotions were enthusiastic and sublime. Three minutes and a half had only elapsed during the experiment, but, from the relative vividness of the recollected ideas, it appeared much longer to him. Not more than half of the nitrous oxyd was consumed. After a minute, before the thrilling of the extremities had disappeared, he breathed the remainder. Similar sensations were again produced ; he was thrown into the pleasurable trance, which continued longer than before. He

ate his dinner with great appetite, found himself unusually cheerful and active at night, enjoyed profound repose in bed, and awoke in the morning with consciousness of pleasurable existence, which continued more or less through the day.

He has since often breathed the nitrous oxyd, and his susceptibility to it's power is rather increased than diminished. He finds six quarts a full dose, but is rarely able to respire it in any quantity for more than two minutes and a half. The mode of it's operation however is somewhat altered, and is very different at different times. He is scarcely ever excited into violent muscular action; the emotions are generally much less intense and sublime than in the former experiments, and not often connected with thrilling in the extremities. When troubled with indigestion, he was two or three times unpleasantly affected. Cardialgia, eructations, and unpleasant fulness of the head were produced. He has often felt great pleasure when breathing it alone, in darkness and silence, occupied only by ideal existence. In two or three instances, when breathed amidst noise, the sense of hearing has been painfully affected even by moderate intensity of sound. The light of the sun has sometimes been disagreeably dazzling. Whenever breathed after excitement from moral or physical causes, the delight has been often intense and sublime.

Conclusion. From the facts already laid down, it appears that the immediate effects of nitrous oxyd upon the living system are analogous to those of diffusible stimuli: both increase the force of circulation, produce pleasurable feeling, alter the condition of the organs of sensation, and in their most extensive action destroy life. In the mode of operation of nitrous oxyd and diffusible stimuli, considerable differences, however, exist. Diffusible stimuli act immediately on the muscular and nervous fibre: nitrous

oxyd acts upon them only by producing peculiar changes in the composition of the blood. Diffusible stimuli affect that part of the system most powerfully to which they are applied, and act on the whole only by sympathy with that part: nitrous oxyd, in combination with the blood, is universal in it's application and action.

As life depends immediately on certain changes effected in the blood in respiration, and ultimately on the supply of certain nutritive matter by the lymphatics, it is reasonable to conclude, that during the action of stimulating substances, from the increased force of circulation, not only more oxygen, and perhaps nitrogen, must be combined with the blood in respiration, but also more fluid nutritive matter supplied to it in circulation.

By this oxygen and nutritive matter excitability may be kept up; and exhaustion, consequent to excitement, only produced, from a deficiency of some of the nutritive principles, supplied by absorption. Then nitrous oxyd is breathed; nitrogen (which in fluid compounds is carried into the blood by the absorbents) is supplied in respiration; a greater quantity of oxygen is combined with the blood than in common respiration, whilst less carbonic acid and probably less water are evolved. Hence probably a smaller quantity of nutritive matter is required from the absorbents during the excitement from nitrous oxyd, than during the operation of stimulants; and, in consequence, exhaustion from the expenditure of nutritive matter more seldom occasioned.

He has lately endeavoured to ascertain the quantities of nitrogen produced, when nitrous oxyd is respired for a considerable time. In one experiment, when he breathed about four quarts of gas in a glass bell over impregnated water for near a minute, it was diminished to about two quarts, and the residuum extinguished flame.

Now his experiments prove, that, when nitrous oxyd is decomposed by combustible bodies, the quantity of nitrogen evolved is rather greater in volume than the pre-existing nitrous oxyd. Hence much of the nitrogen taken into the system during the respiration of nitrous oxyd must be either carried into new combinations, or given out by the capillary vessels through the skin. The various effects of nitrous oxyd upon different individuals, and upon the same individual at different times, prove that it's powers are capable of being modified, both by the peculiar condition of the organs, and by the state of general feeling. It is probable that pleasurable feeling is uniformly connected with a moderate increase of nervous action; and this increase, when carried to certain limits, produces mixed emotion or sublime pleasure, and beyond occasions absolute pain. From comparing facts, it is likely that individuals possessed of high health and little sensibility will generally be less pleasurable affected by nitrous oxyd, than such as have more sensibility, in whom the emotions will sometimes so far enter the limits of pain as to become sublime; whilst the nervous action in such as have exquisite sensibility will be so much increased as often to produce disagreeable feeling. Modification of the nitrous oxyd by oxygen or common air will probably enable the most delicately sensible to respire it without danger, and even with pleasurable effects; in it's pure form the most robust are unable to respire it with safety for more than five minutes. Hysterical affection is occasioned by it, probably only from the strong emotion produced destroying the power of the will.

The quickness of the operation of the oxyd will probably render it useful in cases of extreme debility, produced by deficiency of common exciting powers; and perhaps when mixed with oxygen or common air, it may

be used to recover persons apparently dead from suffocation by drowning or hanging, as by it's immediate operation the tone of the irritable fibre is increased, and as exhaustion rarely follows the violent muscular motions sometimes produced by it, it may be of use in simple muscular debility. As it appears capable of destroying physical pain, it may be of use in surgical operations where no great effusion of blood takes place.

From the strong inclination of those who have been pleasantly affected by the gas to respire it again, it is evident the pleasure produced is not lost, but that it mingles with the mass of feelings, and becomes intellectual pleasure or hope. The desire of some acquainted with the pleasures of nitrous oxyd has been so great, as to induce them to breathe with eagerness the air remaining in the bags after the respiration of others.

As hydrocarbonat acts as a sedative, and diminishes living action as rapidly as nitrous oxyd increases it, it would follow, that by differently modifying the atmosphere by means of this gas and the oxyd, we should be in possession of a regular series of exciting or depressing powers applicable to every deviation of the constitution from health; but the common theory of excitability is most probably founded on a false generalization. The modifications of diseased action may be infinite and specific in different organs; and hence out of the power of agents operating on the whole of the system.

Pneumatic chemistry in it's application to medicine is an art in infancy, weak, almost useless, but apparently possessed of capabilities of improvement. To be rendered strong and mature she must be nourished by facts, strengthened by exercise, and cautiously directed in the application of her powers by rational scepticism.

Approximations to the composition and weight of the
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aëriform combinations of nitrogen at temperature 55° and atmospheric pressure 30.

	100 Cubic Inches.	Grains.		Nitrogen.	Oxygen.
Nitrogen With Oxygen.	Nitrogen	30.04	100 Grains are composed of		
	Oxygen	35.06			
	Atmospheric air	31.10		73.00	27.00
	Nitrous oxyd	50.20		63.30	36.70
	Nitrous gas	34.26		44.05	55.95
Nitrogen With Hydrogen.	Nitrous acid	76.00		29.50	70.50
	Ammonia	18.05		Nitrogen.	Hydrogen.
				80.00	20.00

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Animalization. This is a process which the animal machine makes use of to convert vegetable matters taken into the stomach for the sake of nutrition into animal matter; and *assimilation* is the translation of alimentary substances, whether produced from the vegetable or animal kingdom, into such a state as renders them similar to the different parts of which they are to become a constituent part.

These processes are supposed to be brought about by a chemical action; and perhaps amongst all the operations which take place in the animal economy, there is no one that resembles the chemical action more than that which

brings about the successive changes aliments undergo, from the instant they are received into the stomach to the period at which, after having traversed the organs of respiration, they only form a part of one homogeneous fluid, the blood, in the system of circulation, which is destined for the nourishing and the repairing of the different parts of the animal body. This conversion of aliment into an animalized fluid, afterwards destined to form the various solids and fluids, is undoubtedly one of the most beautiful, singular, and interesting subjects the living animal machine can offer to the investigation of the chemical physiologist, and is one of those which has always appeared to philosophers the most mysterious to conceive, and the most intricate to unravel, of any of the operations that animal life presents.

It is but a few years ago since it was even foreseen that the science of chemistry would ever be able to furnish any thing that could explain the operation of this function, by which the successive and uninterrupted reproduction of all the parts of the body is brought about. It was necessary that the nature of the atmospheric air should be understood, the office of respiration be known, and the analysis of animal matter and its essential difference from vegetable matter should be clearly indicated; these points being once determined, there was much less difficulty in concluding in what consisted the assimilation of aliments, and this has been effected by the new system of chemistry; but it will be necessary first to give an account of the idea the defenders of the old system had conceived of animalization, in which phlogiston formed as usual a conspicuous part.

Opinion of
Ker.

Ker, the ingenious author of the Dictionary of Chemistry, appears to have formed his idea of animalization from Macquer, who considered the conversion of vegetable matters into animal to be principally effected by

means of a fermentation, or the beginning of a long and unobservable putrefaction, and which originated in the conjectures of Hippocrates and Empedocles.

This chemist has, however, greatly enlarged the plan, and improved the hypothesis of his predecessors. He is of opinion, that when vegetable substances are received as food into the bodies of animals, the changes they undergo, and elaboration they suffer by the animal powers, is a chemical process, which process appears to be *a continually commencing putrefaction, continually checked and subdued*. The signs of this commencing putrefaction, he affirms, are the expulsion of fixed air, the black colour the venous blood acquires, the more disengaged state of phlogiston in animal bodies than in vegetables, whence they receive their food, their greater putrescency, their disposition to give in great quantity volatile alkali by distillation, and phlogisticated air by addition of nitrous acid, which substances are known to be products of putrefaction.

Is an incipient putrefaction.

This putrescency, however, appears to be confined within limits, during life, contrary to the known tendency of animal matters deprived of life, which hasten rapidly to putrefaction; that the vital counteracting causes by which the natural tendency of *animal* matters to putrefaction is continually checked, is owing, in some measure, to the frequent ^{digestion} ~~indigestion~~ of fresh food, especially of vegetables; but as many animals are known to live solely on animal food, and this often in a putrid state, whilst they enjoy health and soundness, there must be another principal cause to be equivalent to so great and uniform an effect, which this chemist affirms to be the *absorption of air by the lungs*. It is observed, that the expulsion of pure air in the form of fixed air, and of a disengaged phlogiston in the form of inflammable gas, are the most considerable phenomena in respect to quantity and dura-

Disengage-
ment of
phlogiston.

tion, which appear in the putrefactive process. In the same manner, the expulsion of pure air in respiration, in the form of fixed air, and the consequent predominancy and disengagement of phlogiston in the body, is the actual state of the animal process. If this predominant phlogiston were not constantly combined with the pure air, which is absorbed by the lungs in respiration, it would proceed as it does in the putrefaction of matters not in living animals, *i. e.* it would form inflammable gas, and phlogisticated air, and act as a ferment in hastening the putrefactive dissolution. The very remarkable effect of inflammable gas in promoting the putrefaction of animal bodies immersed in it, is shown by an experiment described by Sage in the *Mem. de l'Acad. Roy. des Sc. à Paris*, An. 1784; and although it is probable the disengaged phlogiston would, if not combined with inspired pure air, occasion death by some immediate action on the nervous system, yet the livid hue observed in men in asphyxy, or suffocation from foul air, shows that the blood suddenly suffers a chemical alteration.

Putrescency
opposed by
pure air.

Pure air then, according to Ker, is no sooner absorbed than it gives immediate signs of counteracting the first indications of putrescency, which appear in the dark colour of the blood brought into the lungs, by instantaneously changing this colour to a vivid hue. This change of colour from a dark red or black to a florid red, exactly corresponds with the known effects of the different fluids upon the colour of blood. For a dark livid colour is produced by exposing blood out of the body to inflammable gas, fixed air, or phlogisticated air, and a florid red hue is given to blood by pure or atmospherical air. The experiments which have been made by exposing blood to pure air, besides prove, that this fluid has a remarkable power of absorbing this air. Putrefying substances have the same power; for Dr. Priestley observed, that they

diminished the bulk of the mass of air to which they were exposed, notwithstanding substances in that state emit fixed air and inflammable gas. It is by means of this constant counteraction of the putrescency of the blood, according to Ker, that opportunity and time are given for various other gradual changes, combinations, and decompositions to take place; in consequence of which changes the different animal fluids may be supposed to be formed. Thus he conjectures the red part of the blood is first formed in a great measure from the chyle, both being of an oleaginous nature; but with this difference, that the oily matter in the chyle is imperfectly mixed, and consequently gives the usual opaque whiteness mixtures of oil and water generally exhibit; whereas the oil in blood is more perfectly combined with earthy matter, probably by absorption of pure air in respiration. It may be remarked, that these two animal liquors, the chyle and the red blood, contain particles visible by means of the microscope. But a more conclusive operation has been taken notice of, viz. that one of the most immediate effects of famine is to diminish the proportion of the red blood. The superfluous oil of the chyle is separated and deposited in proper cells, without undergoing much alteration. For the tallow of animals which live on vegetables retains the properties of vegetable oils, particularly that of making *hard* soap with mineral alkali; whereas the grease of carnivorous animals, and the oil of fish, seem altered by the animal process, and are capable only of making a *softer* soap. The red particles of the blood, having a sufficient proportion of phlogiston in their composition, are more disposed than the other parts of the blood to putrescency: accordingly, as their phlogiston gradually leaves them, principally to form the fixed air extricated by the lungs, their proportion of the other elements increases, *i. e.* they are gradually resolved into a

Formation
of different
parts.

compound containing less phlogiston, but more earth, water, and air; which compound this chemist conceives to be the coagulable part of the serum, which being soluble in water, mixes with the watery particles received with the food, and forms the serum. In consequence of the dephlogistication of the red blood, by which it is thus supposed to be converted into the coagulable matter, this matter possesses less putrescency, has even some ascendent tendency, and when distilled, leaves a more earthy and less inflammable coal. Some particles of this matter are denser and more easily coagulable than others, and those which coagulate with the least cold, have been called the *fibrous part* of the blood, and are found to envelop the red particles, when blood let out of the veins is cooled. As this matter is thus formed by the decomposition of the red blood, in the circulation, the more the force of the circulation is increased, the more the particles in the blood will be agitated and brought into contact, the more this decomposition will be accelerated, and the larger quantity of this coagulable matter will be formed, a good deal of which will be of the denser kind, till the continuance of the same causes resolves it into other fluids less dense. For this matter also, according to this chemist, although less putrescent than the red blood, nevertheless undergoes gradually its peculiar changes and decompositions, by which more of its phlogiston is evolved, and the remaining elements, earth, air, and water, being in greater proportion, approach more to a saline state, and at last are excreted principally in the form of phosphoric salts, with bases of calcareous earth, fixed and volatile alkali; which accordingly appear in the urine and other excretions, especially after an increased circulation. As the changes of the blood are progressive, the juices must, at different times, assume a variety of forms, and in these different states, they may be secreted

by organs fitted for their peculiar separations by the diversity of the diameters of the secretory vessels, as some authors have conjectured with much plausibility, or other appropriated mechanical structure.

The *gluten* of the flour of wheat seems to be similar to the more dense coagulable matter of the blood in it's texture, it's degree of solubility in water, and in the products it yields by exposure to distillation, viz. volatile alkali and phosphorus. In some animals, as the testaceous, a part of the earth in their composition is entirely separated from the other elements, and appears in it's proper state, forming together with some portion of animal gluten the shells of these animals. A similar kind of glutinous substance is formed by the spontaneous decomposition, to which oily vegetable acids, as cream of tartar and common vinegar, are subject. The tenaceous crust then formed possesses the same texture and chemical qualities as animal or farinaceous gluten. Lastly, the *caseous* part of milk possesses the same properties. In these several animal and vegetable glutens, the earth appears to be the prevalent element in the composition, and their formation seems to constitute one of the more advanced stages in the gradual changes which take place in organic bodies. Such is the opinion of this learned chemist respecting the process of animalization.

The new doctrine of chemistry, so inimical to the phlogistic system, has equally changed the method of explaining the phenomena of animalization, as well as that of other processes, and has substituted in it's place a theory that is much better suited to the facts that have been collected upon that vital function, and to the analysis of the substances that are it's objects, than what could have been done by the old theory.

Opinion of
Halle.

From the experiments of Berthollet, we are indebted for the discovery that it is principally by the presence of

azot that the matters of the animal kingdom differ from the vegetable ; it is therefore necessary first to know, in explaining this subject, by what means azot is found more abundantly in animals, and this being once accounted for, will form the basis of our knowledge on animalization. It may be easily conceived that the difficulty of acquiring this knowledge can only relate to those animals that live on vegetable matter, for the origin or the source of that principle in those animals that feed on the same food as themselves are composed of, *i. e.* on animal food, needs no investigation.

For the attempt to explain the function of animalization upon antiphlogistic principles, we are indebted to Halle, who has collected a number of new truths from the labours of modern chemists, and formed a theory on the influence of the air in the operation by which the aliments are converted into animal substances.

Having introduced his subject with some account of the analogies that subsist between vegetable and animal matters, particularly between vegetable gelatin, and gluten and animal gelatin, and fibrin, which are the principal parts, and those which form with the phosphat of lime the most universal basis of animal solids ; he goes on by observing, that there is a character of resemblance much more important, and for the knowledge of which we are principally indebted to Berthollet. It is, that all vegetable and animal substances serving us for food, and all of those composing our own solids and fluids, except a very few, have one common basis in their composition, which is differently combined, according to the diversity of these substances, and which is susceptible of changing their combination by a great number of different operations. This common basis is that of the oxalic acid, *i. e.* that substance which combined with oxygen, the principle that forms acids, gives rise to the acid, formerly called

Analogy
between
vegetable
and animal
substances.

Have one
common

saccharine acid, but now known by the name of *oxalic* basis, the
acid. oxalic acid.

This basis is that of all nutritive substances in general. The saccharine matter, the mucilage, the fecula, the gelatinous and mucous juices of vegetables, the vegetable gluten, a great number of vegetable acids, and likewise all animal mucilages; their jellies, their fibrous part, their albuminous substance, and the caseous part of milk, have all of them the same principle for a basis, which is that of the oxalic acid. This is proved by the nitric acid.

Likewise, the fat oils of vegetables, the butters, and the animal fats, the analysis of which does not afford exactly the same result, appear, as is attested by several phenomena of the animal economy, to be capable of being transformed into this basis, and from the knowledge that has been acquired on the state of this isolated oxalic basis, there is reason to presume, that if there be not a perfect identity between it and the fat oils, there is only a difference in the combination, the nature of which Lavoisier appears to have nearly determined: this chemist asserts, that this basis, as well as the oils, is formed of hydrogen and carbon, but both in the state of oxyds, and which consequently is the point of resemblance between all substances capable of affording nourishment.

Such is the analogy. As to the difference, we are indebted for this part of the analysis to Berthollet, who, Difference
between
them. pursuing the steps of Bergman and Scheele, has been able to demonstrate the different principles to which the oxalic basis is combined, both in animal and vegetable substances, whilst Fourcroy has likewise contributed to augment the knowledge this important analysis has procured us.

The oxalic basis combined with carbon in vegetables, with azot in animals.

It is demonstrated by the labours of the above chemist, that in all these substances, the oxalic basis, without changing it's nature, is more particularly combined with two different principles.

1. With the principle of charcoal or *carbon*, the same which, when combined with the basis of vital air, forms carbonic acid.

2. With one of the constituent principles of volatile alkali, or *azot*, which forms the basis of azot gas.

The first, or carbon, is more abundant in vegetable substances; the second, or azot, is found in greater proportion in animal substances. Those which contain carbon in great abundance, and little or no azot, are likewise those which in their spontaneous decomposition give early signs of acescence; those, on the contrary, which contain a great portion of azot, become suddenly alcalescent.

Thus when vegetable substances become animalized, and when our aliments, which are in general less animalized, than ourselves, are assimilated to our own substance, it may be said the change which then takes place in them consists for the most part in their oxalic basis combining with a greater proportion of the basis of azot gas, or *azot*; whilst on the contrary, it loses a part of the principle of charcoal, or *carbon*, to which it might be united: on considering, therefore, that on analysis, if either the one or the other of these principles be separated from the oxalic basis to which they are united, the combinations into which they pass, almost always give rise to some elastic fluids; it will be readily conceived, how much the consideration of these fluids in the animal economy ought to attract the attention.

of physicians, and how it may facilitate the knowledge of the most important phenomena of our functions.

Halle having compared, in the manner above mentioned, the different substances that enter into the composition of our aliments, and into that of our organs, which he calls the first order of facts, continues the subject by the second order of facts, comprehending

First and
second or-
der of facts.

1. The state of the elastic fluids contained in the alimentary canal.
2. The changes the air undergoes during respiration.
3. The alterations it undergoes in it's contact with the skin.

With respect to the *first*. This chemist informs us, the observations which Jurine of Geneva made on the state of the elastic fluids contained in the intestinal canal, were formed from some experiments made on a strong hearty person who had died suddenly during a cold night, and which were compared with those the dissection of several other bodies offered, under different circumstances, but who died in good health.

These experiments present these remarkable results, that of the elastic fluids contained in the intestinal canal,

1. The respective proportion of vital air always diminishes progressively from the stomach to the great intestines :
2. The respective proportion of azot gas always increases progressively from the stomach to the great intestines :
3. The proportion of the hydrogen gas in general augments from the stomach to the small intestines, and diminishes from them to the great intestines :
4. The proportion of carbonic acid gas is the most variable of all in different subjects; it was very strong in the stomach of the subject that died suddenly, but very weak in the rest of the intestinal canal :
5. It appears that there exists a little alkaline or ammoniacal gas in the canal of the last intestines.

Such is the result of these experiments, made by lime water and the nitrous gas.

With respect to the *second*, it was remarked by Priestley, that respiration produced azot gas. Lavoisier and de la Place proved, that during that process, carbonic acid gas was formed at the expense of the vital air, and the experiments were repeated by Jürine. Hence it appears that respiration alters the atmospheric air in three manners. 1. The portion of vital air, which makes a little more than one quarter of this fluid, is sensibly diminished. 2. Carbonic acid gas is formed in proportion to this diminution of vital air. 3. A new quantity of azot gas is formed, which ought not to be attributed solely to the change in proportion between the two constituent parts of the atmosphere, but which is, in reality, an additional quantity. These alterations in the respired air do not all take place in the same instant of time. The two first, which are absolutely simultaneous, first take place, as they depend entirely upon each other. When the portion of vital air in the respirable air diminishes, the quantity of carbonic acid produced by respiration diminishes likewise; but on the contrary, the disengagement of azot gas progressively increases, and augments the more, as there is less carbonic acid formed, so that the first portions of vital air appear to be employed in disengaging the carbonic acid, whilst the last are disengaging the azot. This effect not only takes place in the ordinary atmospheric air, which naturally contains more than two thirds of azot gas, it equally takes place in vital-air, where the production of azot gas can only be the product of respiration. It has likewise been observed, that in the action that finishes digestion, the respired air received a greater proportion of carbonic acid, and on the contrary, in the action of fever, it received a greater proportion of azot gas.

Lastly, with respect to the *third*, Jurine has put it out of all doubt, that during the contact of the skin with the external air, carbonic acid is formed, and that more is formed in proportion to the greater activity of the functions of the cutaneous organs. When the experiments of Jurine are compared with the manner in which Ingenhoufz made his observations on the same subject, it is easily perceived how the results obtained by these two philosophers may be perfectly reconciled, and upon what the difference depends that exists between their conclusions. It is evident that to the manner in which Ingenhoufz made his experiments the disappearance of the carbonic acid was owing.

3. Halle, after having thus cited the above general facts, lays down the consequences respecting the assimilation of the aliment. He observes, that after having remarked, that the oxalic basis, the common principle of almost all nutritive substances, as well as of those that compose our organs, is principally combined, in the one, with the basis of carbonic acid or carbon, in the other, with the basis of azot gas, or azot, and that the proportion of this last formed one of the principal characters of animalization; the next circumstance is to consider the manner of their separation.

It is well known there are different ways of separating these two principles from the oxalic basis with which they are united, whether in our aliments or in our organs. That this separation is principally brought about by the aid of bodies containing the basis of vital air, viz. oxygen.

In the common chemical analysis of substances the nitric acid is used to furnish this basis with more facility.

Consequences deduced from them.

Separation of the different bases by oxygen.

In the grand operations of nature it is furnished by the atmospheric air, and by water. Wherever it is the atmospheric air that disengages the carbon, carbonic acid is formed, or if it disengages the azot, azot gas. Wherever it is water that furnishes the basis of vital air, hydrogen

gas is disengaged; and wherever hydrogen is disengaged at the same time as azot, and combines with it, ammonia or volatile alkali is produced.

The separation being well understood, the next is to examine what passes in the human body.

Proportion
of vital air
in the intestines.

In the intestinal canal the proportion of vital air diminishes successively from the stomach to the extremity of the intestinal canal, and at this extremity there is no trace of it; thus the vital air, or it's basis oxygen, forms combinations in this passage, and what is the consequence?

It's combinations.

In the stomach, where the aliments still possess their former properties and mix with the juices, of the nature of which there is much incertitude, a portion of *carbonic acid* is disengaged; the principle, carbon, that unites with the vital air to form this gas, appears to come from the aliment, and if the proportion be not constant, it arises from the aliments not always being the same.

In the small intestines into which the bile, one of the known humours that carries the most evidently the animal character, flows with several other secretions, and where the aliments, intimately penetrated with these humours, form a very liquid mass, azot and hydrogen gases are disengaged. One part of the matters contained in this canal being of the number of those that contain the basis of azot gas or azot, may consequently give rise to the extrication of the azot gas, and these same matters forming a heated mass and in a liquid state are the best adapted to bring about the decomposition of the water. The water being thus decomposed gives rise to inflammable gas, and at the same time furnishes the mass of animal juices and aliments with a portion of the basis of vital air or oxygen, which forms a combination whilst the azot escapes.

Lastly, in the great intestines, where the excrementitious mass, by it's odour and products, announces the animal character, the quantity of azot gas increases, but

the inflammable gas diminishes a little, either because the matters being less liquid favour less the decomposition of water, or because a part of the hydrogen combined with the azot forms ammonia or alkaline gas; on the contrary, in certain diarrhœas, the air let loose from the rectum bearing an hepatic odour, is a proof that a very large proportion of sulphurated hydrogen gas is formed in the great intestines. But these matters being then more liquid, the decomposition of the water continues to take place beyond the small intestines.

Thus in the alimentary canal the vital air, whether it be free and arising from the atmospheric air swallowed with the aliments, or disengaged afterwards by the decomposition of water, combines both with the animal secretions and with the aliments confounded with them in the intestinal canal, and at first separates from the alimentary matters a portion of their carbon, with which it unites to form the carbonic acid, afterwards disengaging azot from the intestinal secretions, it favours it's combination with the alimentary matters that receive it in lieu of the carbon, a portion of which they have lost. In this manner the aliments that nourish us commence their incipient animalization, the degree of which, Halle is of opinion, might be estimated, if the nature of the chyle, which is the result, was perfectly understood.

4. Conclusion. It appears therefore to this chemical Conclusion. physiologist, from what has been above stated, that a great part of the process producing the assimilation of aliments, is performed in the *intestinal canal*, in the *organs of respiration*, and upon the *surface of the skin*. That in these three organized parts, the atmospheric air, and particularly the vital part of this air, is the principal instrument of the combinations by which the assimilation is brought about; that it probably acts by taking away from the alimentary matter a portion of it's carbonic

principle, and by facilitating it's combination with the overplus azot of the animal humours, and consequently, that in this common operation, the execution of which is divided between three different organs, but founded in all upon the same principles, a reciprocal change takes place at the same time, as well in the substance of the aliment as in that of the animal humours; by which the one being animalized, and the others losing, as it were, the excess of their animalization, all of them are brought to the same point, and appear mutually assimilated.

Imperfection of this theory.

This chemist, in delivering his theory to the world, does not presume to think that it explains the formation of all the products of animal assimilation, he allows, it neither accounts for the production of the phosphoric salts, nor that of the fat matter analogous to spermaceti, found by Fourcroy in the liver and bile; nor does it explain the manner in which the other animal products are modified, on which modern chemistry has at present cast no light; hence it is incomplete. Such is the manner by which Halle has attempted to explain the mechanism of the assimilation of aliments, and of the change they undergo in their nature, and in which it is to be observed, that although he has made use of the discoveries of Scheele, Bergman, Lavoisier, Priestley, and Berthollet, yet he is one of the first that has embraced so great an extent of operations at the same time respecting the animal functions, and that it was impossible from the present state of facts, that so difficult a problem as that of animalization could be resolved by the few materials he was in possession of.

Observations of Fourcroy upon it.

Fourcroy, who had perhaps a better opportunity of becoming acquainted with facts than Halle, and who had the advantage of later discoveries, has made some restrictions and observations upon the hypothesis of the latter. He thinks it necessary to observe, that in referring all substances composed of the vegetable and animal

kingdom to what Halle calls the *oxalic basis* or *oxalic radical*, this philosopher could only have in view the fixing a striking analogy between all substances; but as the considering of it in this light without some modifications might lead to error, it is necessary to explain how far the truth is able to carry us.

By the *oxalic basis* or *radical* is understood a matter composed of hydrogen and carbon, which when united with a large proportion of oxygen, gives rise to the *oxalic acid*, and which plays the same part in this acid as sulphur, phosphorus, charcoal, or arsenic does in the sulphuric, phosphoric, carbonic, and arsenic acids. If all animal and vegetable matters can be considered as the *oxalic basis*, it can only be as containing the *carbonated hydrogenous* combination constituting this basis. But it would be erroneous to suppose that this *carbonated hydrogen* is equally composed, as to the proportion of these two principles, and consequently equally ready to form the *oxalic acid* on the addition of oxygen, in all these matters. On the first Part.

The combination of hydrogen and of carbon that forms the general basis of organized substances is not homogeneous in all of them; it differs either in the proportion of one or other of the primitive principles, or in the addition of a greater or less quantity of azot, or lastly, in the proportion of the oxygen it already contains; hence to be converted into *oxalic acid*, it is not sufficient constantly to add oxygen and an equal quantity of oxygen to it. For the one it is necessary that a certain proportion of hydrogen or carbon be disengaged, according as the one or the other exceeds the quantity that ought to form the true *oxalic radical*; for the other to disengage a portion of these two principles; for a third order of these substances to take away or separate at first the azot that does not appear to enter into the *oxalic acid*. Thus,

when by means of the nitric acid, the gums, sugar, or starch, are converted into oxalic acid, much carbonic acid is disengaged, because these matters contain much more carbon than is necessary for the oxalic radical; when by means of the same nitric acid the same process is applied to the oils, butters, fats, resins, &c., a great deal of hydrogen and carbonic acid gases is disengaged, a proof of there being more hydrogen and carbon than are necessary for the oxalic radical; lastly, when the nitric acid is made to act on vegetable gluten, elastic gum, muscular flesh, and all other animal matters, these matters are not converted into oxalic acid until they have given out azot and carbonic acid gases, because they contain azot that does not enter into the formation of the oxalic acid, and more carbon than this acid has need of: and it is in this manner the nature of the oxalic radical is to be looked upon, as far as Halle conceives it to exist in all matters considered as aliments, whilst what has been said upon the subject ought only to refer to the following proposition, viz. that all alimentary matters contain that, which, by the addition of oxygen, forms the oxalic acid.

On the second part.

Since the facts related by Halle on respiration, that function has been much better investigated by the united labours of Lavoisier and Seguin. During respiration, water is undoubtedly formed, and there is a disengagement of hydrogen as well as of carbon from the blood. This effect resembles that which takes place in all vegetable matters exposed to the air. It even appears to Fourcroy, that hydrogen burns more easily than carbon, at least in making the analogy respecting vegetable substances. He allows, however, that this formation of carbonic acid and water during respiration is not as yet supported by any positive experiments. There are even some who think that the vital air is wholly absorbed by

the lungs, that in the course of circulation it is by degrees converted into carbonic acid, and that it is afterwards evacuated by the lungs. This opinion, it is evident, is very different from that which explains the formation of the carbonic acid to be effected by the pulmonary organ, owing to the carbon disengaged from the blood afterward uniting with the atmospheric oxygen. The observation upon what passes during the respiration of the great grasshopper (*locusta vermicivora* of Geoffroy) by Vauquelin, appears to authorize this last opinion. He found a canal which conducts the air immediately from the trachea to the stomach, and he believes with much probability, that the air serves to the assimilation of the aliments. If the immediate combination with the mass of aliments or of the chyle be necessary to complete digestion, or to assimilation, as some facts appear to indicate, and as several philosophers are of opinion, it appears that the vital air really penetrates the lungs and combines with the blood, which at the same time exhales carbonic acid. To conclude, it is sufficient for the conclusions drawn by Halle in whatever manner these things are effected, that there be some means during respiration of exhaling carbon. Lavoisier has confirmed, by his last experiments on respiration and transpiration, the result of those of Jurine, and it appears incontestably, according to Fourcroy, that the process which takes place on the skin affords a similar phenomenon to what passes in the lungs, *i. e.* a formation or a disengagement of carbonic acid. It may be possible that three effects concur at the same time in this process of assimilation, for which it is proved that the pulmonary and cutaneous organs are in a great measure destined. Perhaps there is a separation of carbon and hydrogen from the lungs; perhaps oxygen may penetrate at the same time, which uniting by degrees with the carbon of the blood during respiration, after-

ward flows out in torrents through the vessels of the whole surface of the skin. (*Vide* respiration.)

On the
third part.

Fourcroy is of opinion that Halle, in attributing the beginning of assimilation brought about in the stomach and intestines in great part to the decomposition of water, cannot support his conjecture; and indeed, it is only upon the presence of carbonic acid, hydrogen, and ammoniacal gases in the cavity of these viscera, that he offers it. It is necessary to remark, that it is founded upon an observation made by Jurine only on one case, and that it would not be reasoning with much precision to apply it as a general rule. It may be presumed, that the existence of the gases is nearly the same in the course of the alimentary canal of all subjects with that which Jurine found in his subject; but there is no proof that the production of these intestinal gases are owing to the decomposition of water, nor even that the difference of these gases in the different parts of the canal depends upon the state of the water.

Fourcroy's
explanation.

Fourcroy is of opinion, that the primary effects of digestion, which ought not to be confounded with those of assimilation, properly so called, may be explained without having recourse to the decomposition of water. Four principal phenomena take place in the aliments during their residence in the stomach and intestines.

1st. The aliments are softened and dissolved into a kind of homogeneous pulp in the intestines.

2d. Their character is changed by the gastric menstruum.

3d. This solution is decomposed in the small intestines by the bile, which separates the alimentary part from the excrementitious.

4th. The chylous matter is absorbed by the lymphatics in the large intestines, and the excrementitious matter is forced down, carrying with it the fat and colouring matter

of the bile. The bile conveyed into the blood undergoes a change in the lungs. The aliments themselves may be the source of the gases contained in the alimentary tube.

This chyle being poured into the blood, and mixed with it as the alimentary matters were mixed with the animal secretions in the intestines, is then acted upon by means of respiration. During that process, the vital air forms combinations, carbonic acid and azot are disengaged, but both do not appear internally at the same time. The azot gas only appears when the quantity of carbonic acid formed by the vital air, and mixed with the respired air, diminishes in this air the property of disengaging fresh acid from the lungs, which is the case when bad air is breathed. Then the azot, which is probably also disengaged, but which combined with the chyle in proportion as this lost it's carbonaceous principle, finding no more to combine with, departs with the air in the form of gas.

It is therefore probable that in this case the principle of the carbon is furnished by the chyle, and the azot by the blood, and that a real exchange is made as in the process of digestion, *i. e.* the chyle, on losing a part of it's carbon, receives in *lieu* of it the azot separated from the blood, and by this mechanism is animalized and assimilated. It may be said that the blood likewise assimilates itself, because without this exchange, which deprives it of an excess of azot, it would be too much animalized, and at last become alkalized, which, in effect, always takes place when a long abstinence, or food which is too much animalized, prevents the humours from receiving their necessary temperature by the mixture of a mild chyle.

It may be asked, if the respiration would cease to pro-

duce carbonic acid gas, in consequence of a long fast, and at last only produce azot gas, which would seem to be the consequence of this system. Experiments are wanting to answer this question; but presumption, and two facts stated by Jurine, almost assure the affirmative. The one proves, that in the process that follows the digestion of the aliment, and which is accompanied by a sensible increase of heat, and an accelerated pulse, the proportion of carbonic acid formed by the respiration in equal quantities of air, is much greater. The other states, that in fevers, the contrary takes place, for the proportion of carbonic acid is diminished, and that of azot gas increased.

After this important operation, follows that which is the result of the functions of the skin. From the surface of this organ, the vital air likewise disengages a portion of the carbonic principle, with which it forms carbonic acid; and if it be true, as an experiment of Dr. Priestley appears to prove, although contradicted by those of Cruickshanks and Jurine, that the air which has remained in contact with the skin appears, on trying it with nitrous, to be meliorated, and to have lost during this contact a part of its azot gas, the consequence would also be, that the humours become animalized in the skin by a mechanism analogous to those of digestion and respiration; at least it appears certain, that a disengagement of the carbonaceous principle really takes place in this organ, but the ignorance which covers the real nature of cutaneous perspiration, still involves this subject in obscurity. *Vide Respiration.*

Such are the modifications made by Fourcroy on the system of Halle, and the observations which the state of the science allowed him to make on the process of animalization. The facts which have since been brought to

light, are very few, and are scarcely sufficient to afford any further explanation than what this chemist has given us; before, however, this article is concluded, it will be necessary to mention the little that remains. Conclusion.

It is the opinion of several of the most celebrated chemists, and particularly of Parmentier and Deyeux, that the different solids and fluids of the body are created by the process of animalization from the remote, and not from the proximate parts, and consequently, that the vital organization does not take from the aliments albumen, gelatin, fibrin, sulphur, phosphorus, soda, lime, or iron, all of which they look upon as compositions, but only their ultimate parts which are necessary for their formation. Opinion of
Parmentier
and Deyeux,

Thus, in the blood, the different substances it contains are not extracted immediately from the aliments, since in spite of their infinite variety, this fluid, whatever be its origin, constantly furnishes the same principles on analysis, and they even appear so necessary to its composition, as not to be able to exist without them. Hence these chemists think, that it will be useless in future to endeavour to search in aliments and drinks for such of their parts as ought to serve in the formation of the chyle, the blood, bile, &c., or to pretend to give a reason for the transformation of the one into the other, without changing their nature. Before undergoing this transformation, it is necessary for these substances to be exposed to the action of the stomach and intestines, to pass through all the periods of decomposition, and that the gaseous materials, or æriform fluids arising, undergo a certain fabrication in the different organs, so as to form the various matters of the body, with modifications peculiar to each individual species, according to its physical constitution, whether healthy or vitiated by some morbid affection.

Other opinions.

It has already been asserted, that the remote parts of animal substances are reduced to nine, viz. azot, oxygen, hydrogen, carbon, soda, sulphur, phosphorus, lime, and iron, and that the principal difference between animals and vegetables consisted in the preference or proportion of azot, which the first contained in such large quantity.

It might therefore be concluded, that the grand process of animalization consisted in the fixation of azot, and the addition of it as the principal phenomena of animal organism; but it has been observed by the latest physiological chemists, that this phenomenon ought not to be considered so much the effect of the fixation of a new quantity of this principle, as the subtraction of the other principles, by which the proportion of the first must be in consequence increased. It is thus, for instance, that the function of respiration, by gradually disengaging a great quantity of hydrogen and carbon, which, by uniting the one with the oxygen to form water, the other with another portion of oxygen to form carbonic acid, must necessarily increase the proportion of azot. A large proportion of this principle being thus accumulated, is ready to be united with more or less of the other remote parts in different proportions, to form the various animal substances of which a body is composed.

Humboldt.

According to Humboldt, this union by the function of animalization is brought about by the intermedium of the galvanic fluid. Thus the carbon and hydrogen, combined by means of this galvanic fluid, form oils. The hydrogen and carbon, combined with the oxygen by the same means, form acids. The hydrogen, combined with the azot, forms soda, and so of the composition of the rest of animal substances, all being formed by the intervention of this fluid, the nature and properties of which are at present not understood, although this chemist looks upon it to be the nervous fluid. With respect to lime

and iron, he does not consider them as new products in the animal body, but as furnished by the aliments. De la Metherie, however, as well as several other chemists, affirms, that the vital power is able by certain organized parts to form these two substances as well as sulphur and phosphorus, and of course that they are as well as soda composed of remote parts; and this conjecture is rendered very probable by several late experiments: thus Vauquelin found, that the formation of both lime and phosphorus was effected by the function of animalization in the hen (*vide* Fœces), and the large quantity of the phosphat of lime found in milk, and the shells of all animals, which cannot be accounted for by any other means, appears greatly to support the hypothesis, that it is the product of the vital powers; whilst Fourcroy attributes the absence of the phosphoric acid in the blood of the fœtus to the want of respiration. With respect to soda, it is only by the same way of explanation that its presence can be accounted for in graminivorous animals; and as to sulphur and iron, there is great suspicion that they are of the same manufactory, and fabricated by the same powers applied to a different organization. The same may be said of the acids, &c.

Hence it appears, that the organism necessary to animalization has the power of reducing aliments to their remote component parts, and of forming or creating new substances from them; but the sublime process that produces all these combinations, the mechanism by which these transmutations, modifications, and assimilations are so constantly executed, and with so much harmony, in the organized world, are still secrets which we are not able to penetrate.

First Part of a Dictionary of Chemistry, &c. by J. Ker, F.R.S. & S.A. Birmingham, p. 192. Animalization. 1789.
—Essai de Theorie sur l'Animalization et l'Assimilation

des Aliments, par M. Halle, M. D. *Annal. de Chimie.* tom. 2. p. 158.—*Encyclop. Méthod.* tom. 2. *Chimie.* p. 308. Paris, 1792.—Humboldt, &c. Versuch einer Physifchen Darstellung der Lebenskräfte, &c. extracted in the *Journal de Physique*, p. 32. art. *Physiologie Animale.* tom. *xlvi.* An 7. de la République.

DEATH AND PUTREFACTION.

It was the opinion of most of the ancients, that no-
 thing perished during corruption. Pythagoras asserted
 there was only a change in the modifications of matter,
 and that real annihilation was impossible. Plato relates
 it as an ancient tradition, that the living spring from the
 dead, and the dead from the living, and that this is the
 constant circle of nature. Hippocrates thought that all
 animated or living animals, being composed of two prin-
 ciples, fire and water, their qualities communicated with
 each other, affording that infinite variety which appears
 in all the beings of the world ; and that at death nothing
 perishes, but the parts only change their form by mixing
 or separating from each other. Diogenes, Apollonius,
 and Parmenides seem to have held similar opinions.
 Aristotle's ideas were not different, for he says, with
 respect to substances, that the generation of the one is the
 corruption of the other, and *vice versa*.

Opinions of
 the ancients
 on death.

Hippocra-
 tes.

Diogenes
 and Parme-
 nides.
 Aristotle.

Among the Roman authors, Lucretius, in his philoso-
 phical poem, called *The Nature of Things*, has beauti-
 fully described these ideas of the Greeks.

Lucretius.

“ Besides, as nothing nature's power creates,
 So death dissolves, but not annihilates.
 For could the substances of bodies die,
 They presently would vanish from our eye ;
 Dissolving, without force, they'd perish all,
 And silently into their nothing fall.—

“ If all things, over which long years prevail,
 Did wholly perish, and their matter fail,
 How could the powers of all-kind Venus breed
 A constant race of animal to succeed ?

Or how the earth eternally supply,
With constant food, each his necessity?—

“ But since the seed’s eternal, and the frame
Of bodies, and their union not the same,
Things may secure and free from danger stand,
Until some envious force shall break the band,
Thus death dissolves alone, death breaks the chain
And scatters things to their first seeds again.”

CREECH.

Moderns.
Leibnitz.

Leibnitz, among the moderns, has expressed similar ideas. All things are composed of monads, according to this philosopher, which are simple, indivisible substances; they are the real elements of nature, and as such there is no fear of their dissolution. There can be no conception of a simple substance perishing naturally, but every thing that perishes, perishes by dissolution into its simple parts, and every thing that is formed, is formed by composition. Monads, therefore, can only exist or cease an instant, by creation, or annihilation, each monad being in a continued change or vicissitude. Hence it appears, that neither the ancients nor Leibnitz, although they had no idea of the composition of animal substances, ever thought that death was their extinction, but that they again revived under new forms and circumstances.

Signs of
death.

Death may be defined the absence of life, and as it is of great moment to be able to ascertain it with certainty, several methods have been proved to enable the physician to distinguish between its apparent and real state. Behrends and Creve were the first to present to the world galvanism as the proper test; the latter in particular has made many experiments to ascertain the fact. This method is remarkable for its simplicity and convenience. Upon any anxiety respecting a suspicion of a body being not dead, a naked nerve is put into contact with a pair of

metallic rods composed of silver and zinc, and this will resolve the important problem, whether any irritability still remains, and consequently whether the recovery of the corpse be possible. Humboldt, however, although he rejects this as an infallible guide, is of opinion, that it will ascertain the object to a great degree of probability, and hence recommends it's employment as of great use.

The only certain sign of death is putridity. It's presence never deceives. When the vital principle, or as Hippocrates calls it, the vital flame, is extinguished in animals, their spontaneous decomposition commences, and this is called the putrid fermentation, or putrefaction. The object of nature in submitting them to this process, appears to be, to restore to their primitive elements what life had united, by means of it's different functions, to form a composite organized body. The matters, therefore, that formed the bodies of animals, are reduced to their primitive simple state, that in process of time, by uniting again with life, through organization, they may be employed in the formation of new complex bodies, whether of the vegetable or animal species; and this would seem to be the speediest process by which the ultimate parts of bodies, no longer susceptible of being united to life under one particular form, are translated to another. Thus is nature a series of revolutions, a succession of composition and decomposition, of production, and of destruction.

Putridity
the only cer-
tain sign of
it.

There are a number of authors who have written on putrefaction, the principal of which are Beccher, Stahl, Hales, Pringle, Macbride, Geber, Beaumè, and Gardani, some of which have described with great care many of the phenomena that accompany the putrid change in different bodies; but although they have in some measure cleared this subject of the obscurity it was in before the time of Bacon, many more experiments and observations are necessary, to give a full and satisfactory explanation of

Authors on
putrefac-
tion.

the circumstances attending this spontaneous operation of nature. Their great merit has, perhaps, been to point out the way to others who are desirous of attempting a more minute investigation.

Stahl. As upon all other subjects, there have been various opinions respecting the nature of putrefaction. Stahl affirmed it to be a real fermentation, and he considered it as the end or last stage which all animal and vegetable substances are made to undergo by the fermentative processes; and almost all the later chemists, such as Weigel, Gmelin, Macquer, and Morveau, seem to have been of the same opinion.

Boerhaave. Boerhaave asserted that it was not a fermentative process, but that it was essentially different from it, and he appealed to well known facts in his support. Scopoli sided with Boerhaave, forming his decision from the same circumstances, viz. that putrefaction disengages volatile alkali, decomposes all the fixed parts of organized bodies, and produces nothing but earth, and some effluvia, which though most disagreeable, and even poisons to the human body, yet being imbibed by the earth and vegetable creation, give life to a new race of beings; whilst, on the contrary, during the fermentative process, the fibrous texture of substances remain undecomposed, and the productions are only fixed air, wine, spirits of wine, and vinegar. It would appear, however, that Stahl did not look upon putrefaction to be different from the vinous and acetous fermentations, and that they were entirely independent on each other, but only regarded the three as being principal degrees of the same fermentative motion by which all composed bodies are dissolved and reduced to the same state; hence, that putrefaction was a kind of fermentation or rather the last stage of that process, beginning with the vinous, going through the acetous, and ending with the last stage of putridity. It

has likewise been alleged, that if it be a fermentation, it must necessarily be a distinct kind, since we frequently observe it taking place, where neither of the other stages had preceded it, which proves that in some cases at least, it must be entirely independent of, and unconnected with them. Putrefaction has likewise been regarded as a species of ignition: it is said that the power it has of converting every thing into earth, is evidently performed by an expansive power, that in consequence of this, the body first swells, then bursts; vapours are extricated and fly off, and the particles fall asunder from each other, which are the very effects the action of fire produces upon any combustible body; hence it is probable that the agent in the air considered as the cause of putrefaction, is no other than the fire itself; *i. e.* the ethereal fluid expanding itself every where, and that instead of an emission of flame, which ignition is attended with, putrefaction is accompanied with a production of azotic gas.

All organized, and particularly animal substances, undergo the putrid fermentation; and Leonhardi is of opinion, that a slight acetous fermentation takes place, previous to it; this may proceed from the gelatin, which under certain circumstances, as in broth, is said to be subject to the acetous process.

The putrefaction or spontaneous decomposition of animal substances, may be divided into as many species as there are chemical agents in nature capable of producing it, thus, when it takes place in the open air, it may be called, *atmospheric* putrefaction. But when in consequence of bodies not being exposed to the external air, a decomposition takes place amongst their component parts, and new combinations arise, the products are totally different. In these cases, the principal effect is their being deprived of their azot; such is the case when

Subjects of
putrefac-
tion.

Various
kinds of pu-
trefaction.

bodies are heaped together in the earth, and hence it may be called *terraneous* putrefaction; or under water, giving rise to the *aqueous* putrefaction. In all these cases where the air is excluded, a more or less oily mass is produced. The same took place during the *internal* putrefaction of the human liver, as described by Fourcroy.

1. Atmo-
spheric pu-
trefaction.

1. *Atmospheric Putrefaction.* When an animal substance is exposed to the atmospheric air, so as to give rise to it's spontaneous decomposition, it passes with more or less rapidity through the following changes, particularly affecting it's colour, smell, and consistence. It becomes of a paler colour, it's consistence is diminished; if it be solid as flesh, for instance, it softens, and a ferous kind of matter oozes out, it's colour quickly changes, it becomes relaxed in it's texture, and it's organization is destroyed; it has a faint and disagreeable smell, it sinks down and is diminished in bulk, and it's smell becomes stronger and alkaline. If the substance be contained in a close vessel, the progress of putrefaction, according to Fourcroy, seems to slacken at this stage, and no other smell but that of a pungent alkali is perceived; it effervesces with acids, and changes the blue of violets to a green colour. If, however, the communication of the air be admitted, the urinous exhalation is dissipated, and a peculiar putrid smell extends itself with great impetuosity, and of the most insupportable kind. This smell continues a long time, spreads every where, pervades every place, and affects the healths of living animals so as to produce putrid diseases. This smell Fourcroy observes, is connected, and as it were confined by the volatile alkali, which when volatilized, is succeeded by the putrefactive process, becoming active a second time, the substance suddenly swells, is filled with bubbles of air, but soon after subsides again. The colour now changes, the fibrous texture of

the flesh is scarcely to be distinguished, and the whole is converted into a soft pulpy brown, or greenish matter, of the consistence of poultice, with a faint, nauseous, and disgusting smell, that is very active and contagious. This smell gradually subsides, the fluid portion of the flesh assumes a kind of consistence; it becomes of a deeper colour, and the whole is finally reduced to a friable matter, somewhat deliquescent, which on being rubbed between the fingers, breaks into a coarse dark powder like earth. This is the last state animal substances undergo during this process, for which a considerable time is necessary. For the total destruction of the whole body of an animal, it is said that eighteen months, two or even three years are scarcely sufficient when exposed to the external air.

During the time animal matters are undergoing the above changes of decomposition, their component parts fly off, or form new combinations, either with the vital air of the atmosphere, or by simple attractions between each of their principles, they form unions amongst themselves, giving rise to simple, binary, and even ternary combinations. The products are carbonic acid gas, ammonia, nitric acid, sulphur, phosphorus, hydrogen gas, and the substances it dissolves, azot gas, Prussian blue and heat, which being disengaged by degrees into the atmosphere, diminish in proportion the mass of animal matters, and there remains an earth behind. Products of it.

1. *Carbonic acid.* This is disengaged from putrefying bodies, particularly from solid parts, in large quantity. Carbonic acid. The quantity appears to be in the inverse proportion of the quantity of hydrogen gas extricated, for at first it is in large proportion, and the hydrogen gas in small proportion, but afterwards the contrary takes place. The first product Lavoisier obtained from the fecal matter of a necessary in a putrid state, was these two gases mixed

together; 11 parts of carbonic acid, and one of azot gas. The temperature was at 8° or 10° of Reaumur. Priestley has likewise ascertained their proportion and quantity. Having let 4 pennywts. 6 grs. of lean mutton become putrid, he obtained $2\frac{1}{2}$ oz. measures of gas, of which $2\frac{1}{2}$ were carbonic acid gas, the remainder hydrogen gas. Corvinus long ago obtained a quantity of elastic fluid, from putrid substances, one of which was imbibed by water, the other not, they were therefore very probably the same gases.

The carbonic acid has been supposed to have already existed in animal substances exposed to putrefaction, and to have been only extricated during that process; but Lavoisier found that new fecal matter would not effervesce with acids, whilst an effervescence took place with it in its old state, which certainly is against this supposition: some chemists, and particularly Berthollet have asserted, that it arises from the decomposition of the water, that the vital air unites with a portion of the carbon of the animal matter, and forms carbonic acid, whilst the other principle of the water, the hydrogen, is set at liberty in the form of a gas; hence two gaseous substances are obtained, the carbonic acid and hydrogen gases. There is, however, some doubt of this origin of the carbonic acid; and other chemists are of opinion the oxygen is supplied by the atmosphere, since there is no extrication of carbonic acid, unless the substances are in contact with the atmospheric air. It is in large quantity in the beginning of putrefaction, at which time it only exists. It is the gas that is often so fatal to people who descend into vaults, and those places where animal substances are left to putrefy.

Ammonia. 2. *Ammonia.* It was long supposed that ammonia already existed in animal substances before putrefaction commenced; but Berthollet found that when fresh; no

animal matter contained it perfectly formed, and that when deprived of azot, by the nitrous acid, they no longer afforded ammonia by any means, particularly by distillation. It has been before observed, that animal substances contained a large portion of azot, and this accounts for the origin of ammonia; the azot combining with the hydrogen of the water, (where oxygen, or at least part of it formed carbonic acid with the carbon,) forms a union, which being let loose, is the volatile alkali so very prevalent amongst putrid substances by its pungent smell. It is necessary, however, for the formation of this alkali, that the two principles meet and unite at the time they are disengaged, and just taking the gaseous form; for if both the azot and hydrogen were enveloped in their solid combination, no union could take place, which happens in those animal matters that have undergone no alteration; *if* on the contrary, one of these two principles is developed without the other, and separates from the matters that contain it in the form of an elastic fluid, the production of this alkali is equally prevented, as is the case when the nitric acid is used. But by the slow and gradual action of putrefaction, or by that of fire increased by degrees, as in distillation, the intimate union of these two principles is accomplished, by favouring their slow and simultaneous evolution, and by carrying them within the reciprocal attraction of each other. It is from the same circumstances perhaps, that Gaber was not able to discover any ammonia in putrid substances, either in the beginning of that state, or towards the end, and which led him to deny the existence of it at these periods of putrefaction. Crell likewise found it was not to be met with at all periods; he is, however, of opinion, that its presence is to be found as long as the putrid smell continues, whilst Porner affirmed it's presence to be a sign, that the putrefactive process has arrived at its greatest height,

and is approaching to an end. From the facts of the production of ammonia, it appears that nature, by allotting to animal substances the property of forming this alkali, has given one of the principal means of their decomposition, and spontaneous destruction; for as soon as the azot separates to unite with the hydrogen, the bond of their intimate composition is relaxed; this alcalescence may then be looked upon as a sign of great dissolution and perfect disorganization, which cannot take place in animal matters, without bringing on their total destruction.

Probability
of the for-
mation also
of potash
and soda.

There is great reason to believe that, besides this alkali, the two others, viz. potash and soda, may be produced during putrefaction, although their component parts are at present not well ascertained. There is an account by Morveau, in his experiments on the effects of different gases on flesh, that having suspended a piece of lean beef in a bottle, filled with nitrous gas, which was covered with a moist piece of bladder, and well tied, he found on opening it five years after, that crystals of nitre were formed in it; real nitre is likewise found near privies, as particularly instanced by Dr. Wall. The formation of the nitrous acid may be accounted for from the existence of its radical, but that of the *potash* is difficult to explain. Thouvenel, who appears to have observed a similar phenomenon, admits an epoch of *alcalescence* in putrefaction, after that of *accescence*. The same author has observed, that where putrid substances are exposed for the formation of saltpetre, the *mineral alkali* is likewise formed.

Nitric acid.

3. *Nitric acid*. It had long been known that the putrid fermentation was very necessary to the formation of nitre, and Kunckel, Vieussens, and Homberg had remarked that putrid blood when dried and exposed to the air afforded it in large quantity. Juncker relates

that Kunckel having let some blood putrefy, until it was reduced to an earth, lixiviated and evaporated the liquor until a pellicle appeared, and obtained from 100lb. of blood, rather more than 5lb. of crystallized nitre. But the most direct and simple experiment was made by the Commissioners of the Academy: they put some chalk well lixiviated in boiling water into baskets, and exposed them to the vapour of putrid ox blood, at about two feet distant from each other; when at the end of a few months, the chalk was found to contain four or five ounces of saltpetre for each quintal; from which they conclude, that the nitrous acid is produced by the union of the vital and the putrid airs, provided every thing is tranquil, and the atmospheric air is renewed by little at a time, and slowly. Thouvenel made some experiments on this subject, by putting into different vessels air disengaged from putrid matters, with various æriform fluids, and into which he had previously put some alkali or earth, in order to fix the acid, and he found 1. that at the end of a few months, nitrous acid was only formed in that vessel in which was vital or atmospheric air. 2. That chalk always afforded it when exposed to the mixture, and other soluble earths, and alcalis very rarely. 3. That of all animal matters, blood affords it in greatest abundance, and during the longest time. Since the discovery of Berthollet, that azot is so abundant in animal substances, and since the composition of the nitric acid has been found to contain that principle, as one of its component parts, some light has been thrown on this obscure subject; and the formation of this acid is now accounted for by some chemists, from the vital air of the atmosphere uniting with the azot, which is extricated in the form of gas from the putrid matter; whilst others on the contrary, as Fourcroy, allege, that there is a decomposition of the water, and that the oxygen is furnished

by that fluid. It was affirmed by Shaw, that the production of this acid was only during the last stage of putrefaction. It has also been observed, that it is not a quick but a very slow putrid decomposition that produced the greatest quantity of this acid; that a too great degree of moisture, or too long continued, was hurtful; and from the experiments of Crell it appears, that a moderate heat, such as spring and autumn, with a change every fourteen days, or once a month, of the surface of the putrid matter, and a moist atmosphere, were the most favourable to it's generation.

Sulphur.

4. *Sulphur*. According to De la Metherie, this substance has been found in several places where putridity is going on, as on the sides of stalls; and according to Rochefoucault, it was found crystallized on the walls of some old passages at Paris, arising from the effluvia of putrefying substances; it has likewise been observed in the dung of horses, and is supposed to be the produce of an incipient putrefaction.

Phosphorus.

5. *Phosphorus*. The phosphorescent light observed in putrid substances, and particularly in putrid fish, was supposed by Lavoisier to be occasioned by the extrication of phosphorised hydrogen; but Davy accounts for it in a different way. He asserts, this luminous appearance arises from the liberation of nitric phosacid, previously formed during life, by the combination of light with oxygen and nitrogen. He found by experiment that putrefying fish are equally luminous in water, when boiled to expel the air and phosoxygen.

Hydrogen
gas.

6. *Hydrogen gas*. This is another production of putrefaction. It was ascertained by Lavoisier from some experiments made on the fecal matter of a necessity, that the proportion of this gas increases with the progress of putrefaction, and he continued to obtain it for several years after the fixed air had ceased to be produced, al-

though Priestley affirms the contrary. Lavoisier exposed four inches of fecal matter to 24 inches of vital air under mercury, and in ten days there only remained $22\frac{1}{3}$ of the air. This diminution of vital air, by it's exposure to new fecal matter, he attributes to the effect of a small quantity of inflammable air disengaged; for Priestley has observed, that when inflammable air is disengaged slowly from fermentescible substances into vital air, there is an insensible union between these two airs at the moment of the formation of inflammable air; and a further proof of it's being this air which acts on the vital air at this moment is, that if instead of new fecal matter, which affords very little inflammable air, old fecal matter, or that which is a little advanced in putrefaction, be used, it's action on the vital air is greater and more rapid, and a much greater diminution takes place; at the same time the inflammable air, which would have been obtained by the operation in vessels void of vital air, disappears: hence it is probable that it effects by slow means what takes place immediately in case of combustion. (Vide carbonic acid.)

Hydrogen gas has a very disgusting smell, and it is found to be capable of dissolving sulphur, phosphorus, and even carbon, which substance it deposits again on the addition of several chemical agents after the solution has taken place. It is therefore asserted by several chemists, that the disagreeable nauseating and even insupportable stench which arises from substances in a putrid state is owing to hydrogen gas; either in it's free state, or holding in solution sulphur, in which state it is called sulphurous hydrogenous gas; or phosphorus, when it is called phosphorated hydrogenous gas; or carbon, forming carbonated hydrogenous gas. The difference or degree of smell may likewise be attributed to the difference or degree of solution. If the hydrogenous gas be alone, it is perhaps the

least unpleasant; combined with sulphur, it has the smell of rotten eggs; and with phosphorus, that horrid stench is produced peculiar to stinking fish. The carbonated hydrogenous gas no doubt likewise produces it's peculiar smell, but as these odours are generally mixed during putrefaction, they are perhaps only to be distinguished at particular stages of it, when the one or the other predominates.

Azot gas.

7. *Azot gas.* This is obtained from putrefying animal substances either in it's combined state, or united with hydrogen forming ammonia, or with oxygen forming the nitrous acid; it may likewise form other combinations. According to Fourcroy, this gas has a very peculiar and distinct odour resembling fish just beginning to putrefy; it separates a little carbon from animal substances, and it gives the greenish colour to parts, more particularly to the muscles, which is seen during their putrid state: this chemist asserts it has a very deleterious effect on living animals, and Dr. Mitchel of New York, as well as Drs. Hamilton and Currie, are of opinion, that the gaseous oxyd of nitrogen may have the principal share in generating contagious diseases.

Prussian blue.

8. *Prussian blue.* Fourcroy has found Prussian blue in animal substances during putrefaction, and a smell of prussic acid has also been observed; but as all animal substances contain the principles of these two matters, which require only an opportunity for a union, their presence in some cases is not surprising.

Heat.

9. *Heat.* Whether this be a substance or a sensation produced by the repulsive motion of the putrid process, it is found to take place in all matters undergoing that operation, more particularly when in large quantities; this is more evident in dunghills; and we are informed by Munro, that upon thrusting his hand into the flesh of a dead and corrupting whale, he felt a very sensible heat.

10. *Earth.* When the volatile parts, or those capable of becoming so, fly off or form combinations, and escape in the order of their volatility, and the various odours they give rise to have vanished along with them, the putrefactive process is over, nature has performed her purpose, her decomposition is complete, and there remains nothing but an insipid, blackish, and carbonaceous substance, which is called the earth, a species of caput mortuum, which has not been thoroughly examined. It is said to consist of the oily matter, of calcareous phosphat, and the phosphat of soda, united to a portion of the carbonaceous principle.

From observing the phenomena attending putrefaction Boisseau has distinguished four stages. Four stages of putrefaction. The first he calls a tendency to putrefaction, which consists of only a very inconsiderable change, perceptible by a slight faint smell, and a softening of the substance. The second degree he calls the commencement of putrefaction, this is sometimes indicated by marks of acidity, the substances lose somewhat of their weight, become soft and emit a fetid smell; a serous matter exudes from them if in close vessels, or they become dry or dark coloured if exposed to the air, although if the last be moist there is little difference. The third degree he calls the advanced stage of putrefaction, the substance emits a volatile alkaline smell, mixed with a nauseous or putrid aroma, it diminishes and falls into dissolution, the colour changes more and more, and it loses both ⁱⁿ weight and bulk. The fourth degree, or complete putrefaction is known to have taken place by the volatile alkali being entirely and completely dissipated, the fetid smell loses its force, the volume and weight of the substance are considerably diminished, a gelatinous mucus is separated, the mass becomes by degrees dry, and is at length reduced to a friable and earthy matter.

Such are the general stages and effects which nature produces.

Difference
of pheno-
mena.

These phenomena are not however the same in all matters that undergo putrefaction. There is a great difference between the putrefaction of the parts of living animals and that of dead organs. Besides, every humour and every solid part separated from a dead animal has likewise it's peculiar manner of putrefying. The muscular, the membranous, or the parenchymatous texture of the organs; the oily, gelatinous, or albuminous nature of the humours, their consistence, their state with respect to that of the animal which afforded them, all have a more or less great influence on the putrefactive process, ~~and~~ modifying it in a variety of ways, perhaps impossible to be estimated. If to these be added, the state of the air, it's temperature, elasticity, weight, dryness and moisture, with many other circumstances, the actions of which are more or less to be considered, the phenomena will be still more diversified. Hence we may say with Fourcroy, that the history of animal putrefaction is scarcely begun, and demands an immense series of experiments and observations.

Causes as-
signed by
different
authors.

Several causes have been attributed to the production of putrefaction. It was the opinion of some philosophers it was brought about by animalcula and insects; amongst these were Linnæus, Kircher, and Plenciz; this hypothesis, however, was overturned by the experiments of Alexander. According to the opinion of Macbride, fixed air is the fundamental cause of putrefaction; for as he supposes this to be the power of cohesion in bodies by which their parts were kept together, it follows, that when this is extricated, as is the case in all putrefaction, the other component parts must likewise suffer a decomposition, the equilibrium between them being destroyed.

Another opinion was, that phlogiston is the cause of it, and as it was the fashion to attribute almost every chemical phenomenon to the absence or presence of this principle, it was confidently asserted, that the decomposition of bodies is brought about by this phlogistic matter being extricated from them, or in other words, that the absence of phlogiston was the production of putridity. The phlogisticarians, and particularly Ker, explain it in the following manner: they look upon the separation of phlogiston from the other component parts of bodies to be the foundation of this process. When therefore putrefying substances are exposed according to circumstances that favour it, it begins first by an expulsion of fixed air, by which much of the pure air of the organic matter is extricated to unite with the phlogiston for its formation; another part of the phlogiston unites with the water, and, the volatility of both being assisted by the heat of putrefaction, rises in the form of inflammable gas; another portion of phlogiston evolved and freed from its organic composition unites with a portion of air, forming phlogisticated air; some of this phlogiston uniting with a great deal of water, some earth, and less air, forms volatile alkali; the remaining phlogiston attracting slowly the pure air from the atmosphere, forms, with water and the fixed alkali or the pure earth of the organised substance, a saline or calcareous nitre; whilst the greatest part of the earth thus separated from its former combinations remains in its proper form, or rather in a somewhat phlogisticated state. It was then alleged, that the atmospheric air was the grand cause; but according to Weber, this air is not only without effect, unless assisted by warmth and moisture, but from the experiments of Alexander, its free admittance is not indispensibly necessary to putrefaction. Fourcroy, and the French chemists attribute it to the decomposition of water; it is their opi-

nion this fluid is decomposed, that one of it's component parts, the oxygen, seizes the azot of the animal substance, and contributes to the formation of the nitrous acid, and that the other component part, the hydrogen, uniting with a portion of the same azot which abounds, produces the volatile alkali. The great difficulty, however, respecting the decomposition of the water is, that it is unknown how it can take place at so low a temperature; and to shew that oxygen is always imbibed by putrefying substances, it is only necessary to examine the air, which is found to be diminished, and the oxygen to have disappeared, whilst the presence of the atmospheric air is always necessary for putrefaction to take place, and the purer the air, or the larger quantity of oxygen it contains, the sooner and the more rapid is the putrefying process; these are great proofs that this principle acts at least a principal part in it's production; but as before observed, it is not the cause of it.

Morveau, in order to find what action different sorts of airs would have upon animal substances, filled seven large bottles, and suspended in each an ounce of lean beef, he then covered the bottle with a piece of bladder, and tied it, leaving them for five years without being opened, when he found, that

	Grains.
In the vital air, the flesh was reduced to	136
Common air	149
Fixed air	157
Inflammable air	163
Nitrous gas	155
Ammoniacal gas	242
Putrid gas	168

In the vital air, this chemist informs us, the putrid odour was perceived the longest time through the bladder, it was very strong after two months, whilst if that

in the common air be excepted, scarcely any thing was emitted from the others; hence it appears, that the vital and common airs had a great advantage over the others, which agrees with the nature of them determined by other properties. All the pieces of flesh were found to be dry and tending more or less to a black colour, especially that in the vital air, which shows that it had made in that air the greatest progress in putrefaction.

The cause or origin of putrefaction is the resumption of the chemical elective attractions which the component remote parts of bodies had been deprived of by the principle of life, and the consequent formation of new combinations brought about by several accessories, or as they may be called, septic, viz. *moisture, moderate temperature, repose, and a communication with the external air.*

A certain degree of moisture appears necessary to give the component parts the liberty of coming within each other's attraction so as to form new unions with the oxygen of the atmosphere, and also amongst each other; whereas dryness prevents, or rather retards it, as well as too much aqueous fluid; hence the preference of a moist atmosphere.

2. A moderate temperature, such as 65° , is found to be the heat of the atmosphere most favourable to putrefaction. On the contrary, a great degree is apt to volatilize the parts of bodies before they can form a union, and to produce exsiccation; and a low degree, as that near the freezing point, retards it by not giving the parts sufficient activity to form new combinations, whilst congelation stops it altogether.

3. Repose is likewise a great assistant in this process, for without it there is no time for new unions to take place, and a quick succession of air takes away the moisture so necessary, and dries the external parts; a confined air is the greatest promoter of putrefaction.

Distillation
compared
to putrefac-
tion.

4. Bodies will not putrefy in vacuo, hence the atmospheric air is equally necessary with the others, and it is always found to be diminished, as is the case whenever it's oxygen is absorbed, *i. e.* in all processes which the old chemists called phlogistic; and the larger the proportion of oxygen the quicker and more perfect is the putrefaction. It is on this account that great similarity has been observed, particularly by Goddard, between the putrefactive process and the action of fire on the atmosphere during combustion, both converting substances into an earth, and causing an absorption of the oxygen of the atmosphere, and a generation of fixed air; but as the putrefactive process is much slower than either moist or dry distillation, the products are different in some respects, from the great degree of heat not permitting the component parts to form the same unions. They both decompose animal substances and form new compounds. Both in distillation and putrefaction, fixed air, ammonia, hydrogen gas, and sulphureous hydrogen gas are obtained; but in the first, the heat being very powerful, forces more or less carbon from it's combination, which uniting with hydrogen forms an oil more or less empyreumatic, according to the quantity of carbon; whilst in the second, when there is sufficient repose and time for the azot to unite with the oxygen of the atmosphere, the nitric acid is produced.

These four accessories being the grand promoters of putrefaction without which it cannot take place, it follows, that substances which are favourable to these promote putrefaction; and on the contrary, those which impede them, more or less prevent it. It is principally on these grounds that experiments have been made to find what substances promote, and what retard or prevent it; the first have been called septics, the other antiseptics. For many experiments of this kind we are indebted to Prin-

gle, Macbride, Buckholz, Brugnatelli, Spielman, Morveau, &c., but great additions are necessary to determine the relative powers of septic or antiseptic bodies with any degree of precision.

Pringle and Macbride were the first to make experiments to prove what those substances were that opposed putrefaction. In taking the general conclusions not only of the experiments of these two physicians, but of those of Buckholz, Brugnatelli, and Morveau, it appears, that substances which are antiseptic are not only incapable of putrefaction themselves, but they deprive those which promote it of their energy, at least in a greater or less degree; among these are dry earths, acids, alkalis, neutral salts, spirituous liquors, essential and empyreumatic oils, balsams, resins, spices, bitters, astringents, smoke of different kinds, and all gases or airs, except those into which oxygen enters as a constituent part, as the atmospheric air.

All these impede the putrefactive process, at least, animal substances are longer in becoming putrid in them than when exposed to the atmospheric air, &c. It is likewise found, that the fermentation of vegetable substances is increased by a mixture of animal matter, and the putrescency of the latter is corrected by the opposite quality of the former.

By making use of those means, which prevent putrefaction, and by the assistance of those substances that are called antiseptics, the bodies of animals or their parts may be preserved for a great length of time. This has been practised from the earliest ages, by the name of embalming. According to Diodorus Siculus, the ancient Egyptians were accustomed not only to embalm the dead bodies of those animals their superstition had rendered holy, but likewise human bodies which were thus preserved from a spontaneous decomposition, and are so abundantly

Antiseptics.

Preparation of animals.

Art of embalming by the Egyptians.

to be found by the name of mummies. We are informed by Herodotus, as well as the before-mentioned author, that the Egyptians had several methods of embalming the human body, three of which are particularly noticed. To this difference in the process, Leonhardi attributes the different opinions physicians and chemists have had of this ancient operation.

Three methods.

1. A hole was made through the nostrils into the cranium, the brain extracted, and the cranium was filled with the embalming substance. The thorax and abdomen were then deprived of their viscera, except the heart and kidneys; they were washed with Phœnician wine, and filled with sweet-scented resins and aromatics; the opened parts having been afterward sewed up, the body was well washed and cleansed, and placed in natron, which is supposed to have been the mineral alkali united with common salt, and found native in Egypt. In this alkali it remained about 30 days; it was taken out and washed a second time, besmeared over with a gum or resin, carefully enveloped with cotton bandages and placed in a coffin. This method was very expensive, but is the only one that merits the name of embalming.

2. A cheaper way of preserving the body was to introduce various resins, particularly that from the cedar, by the anus, without opening either the belly or thorax, the body was then dried in natron, and afterwards the resin with the corroded intestines were taken away.

3. The cheapest method consisted merely in washing the body, and its exposure to the action of natron, which we are informed destroyed the flesh and only left the skin and bones.

Opinions on the substances employed.

With respect to the embalming substance employed on these occasions there are various opinions. Some, as Rouelle and Vandermonde, look upon it to have been asphaltum mixed with the oil of the cedar seed; whilst

Hardley thinks, with the ancients, it was the resin of this tree, or some other vegetable resin. Belloni and Blumenbach are of opinion that asphaltum was used in common operations as being the cheapest, and that, on particular occasions, the odoriferous vegetable resins were chosen; and the latter chemist, on the examination of ten different mummies, found no asphaltum, but very evident traces of vegetable resins. It is, however, certain that the substances for this purpose were not always of the same kind.

The art of embalming the human body has likewise been attempted by some of the moderns, but the mere ^{Attempted by the moderns.} action of saline bodies, and filling the cavities of the body with aromatic herbs, were found not to be sufficient to preserve it from putrefaction. The best and perhaps the only method worth attention is that pointed out by Dr. ^{Dr. Hunter;} Hunter. As soon as the corpse is become cold and stiff, and before any symptoms of putrefaction appear, it is to be well washed with warm water; one of the large arteries is then to be laid open, and the following injection to be forcibly made to enter the smallest vessels, even those of the cellular membrane. Two parts of the oil of chamomile are to be mixed with eight parts of oil of lavender, and sixteen of oil of rosemary; likewise the oil of turpentine may be either used alone or mixed with a little of the oils of rosemary and lavender; or, to give it a colour, a little cinnabar may be united with the oil of turpentine. The different viscera are in a short time after to be extracted, the intestines to be carefully cleansed of their contents, and the rest of the viscera to be deprived of their moisture by wiping them repeatedly with dry towels; the body is likewise internally to be cleansed of its blood and injected oils, by squeezing the vessels; the arteries are then to be injected as well as the other large vessels that have been cut, with a mixture com-

posed of 6 lb. of oil of turpentine, 5 oz. of turpentine, 11 oz. of cinnabar, 2 oz. of camphor, and 3 lb. of strong spirit of wine; with this likewise the fleshy parts that have been well deprived of any moisture are to be carefully anointed, the vessels of the intestines to be injected, and then to be replaced in their former situation, scattering a sufficient quantity of a powder about them, composed of 10 lb. of yellow resin or pitch, 6 lb. of saltpetre, and 5 oz. of pulverized camphor, so that every vacancy may be perfectly replete with it. Afterward, when a little of the injecting liquor above mentioned has been poured into the thorax and belly, the skin is to be closed, the mouth, pharynx, and larynx syringed and filled with the powder, together with the cavities of the ears, nose, anus, parts of generation, eyes and eyelids, and the whole body, after having been previously washed and rubbed dry, is to be well rubbed with alcohol and camphor, and finally with the oils of rosemary and lavender. The body being thus embalmed, in order to deprive it of any remaining moisture, it is to be laid in a coffin upon some calcined and finely pulverized gypsum, so as to be on all sides about half covered with it; pieces of camphor are to be strewed about, and a range of open bottles filled with volatile oils; the coffin is then to be well closed, having a lid with a glass in it. In about four years the gypsum should be renewed, and when the body is perfectly dry, it may be dispensed with altogether.

Preparation
of animals
by natu-
ralists.

Besides the embalming of the human body, chemistry is able to afford great assistance to the naturalist in the preparation of quadrupeds, birds, and other animals that compose collections of natural history. It affords the most proper means not only of being able to give them duration and consistence, but to make them deviate as little as possible from the living state, that by their attitudes and most natural positions, they may be enabled to

exhibit in great perfection both their instinct and character, circumstances of great importance in the science of natural history.

For these effects, the methods published by Reaumur in the 45th vol. of the *Philosoph. Trans.*, and those related in the *Dict. d'Histoire Naturelle*, when chemically examined, are far from being satisfactory. Independent of the method of embalming proposed by Dr. Hunter just mentioned, which may be applied also to subjects destined for natural collections, several chemists have given directions for that preparation; amongst the principal of which are Kuckham, Chaptal, and Pinel.

Kuckham published a process for the preparation of birds Method of Kuckham. in the 60th vol. of the *Philosoph. Trans.* His composition to preserve them from putrefaction is a mixture composed of a quarter a pound of corros. sub.; half a pound of calcined saltpetre; a quarter of a pound of calcined alum; half a pound of flowers of sulphur; a quarter of a pound of musk; one pound of black pepper, and one pound of pulverized tobacco; these are to be kept in a well-closed glass vessel, and in a dry place. The corrosive sublimate is very fatal to insects; and, according to Pinel, the only objection to Pinel. the mixture is the expense. He therefore substitutes the following in its place; equal parts of corros. subl. or arsenic, calcined alum, camphor, canella, or any other aromatic, are to be pulverized and mixed together. Pinel has likewise made use of a varnish with great success; it was, he informs us, at first kept a secret, and is a very sure means to prevent the generation of insects in the skins of dead animals, or to destroy them when hatched; so that for three or four years, until they can be conveniently placed in the collection they are destined for, the keeping them under cases of glass may be dispensed with. It is composed of the following articles: Four ounces of pulverized arsenic are to be put into one pound of brandy,

the mixture heated gently, some black soap and aloes are then to be added, so as to form a kind of magma, which must be lightly extended whilst warm in the interior of the animal with a brush, the soft parts having been taken away; the same process must be applied to the internal surface of the skin. When used, he recommends it to be diluted with alcohol. Immediately after its use, the preparation should be *mounted*, as the evaporation of the fluid part occasions the skin to become hard and difficult to soften again.

It is with this magma that cotton or flax ought to be impregnated, with which the internal parts of animal bodies are to be filled, and it is found to be far superior to the mixture composed of a solution of camphor in rectified spirit of wine, which is commonly used in this country. It is likewise necessary that the zoologist should be provided with caustic soda, a solution of which corrodes the soft parts, and by uniting with the fat parts forms a species of soap that is afterwards easily taken out by repeated lotions. Chaptal recommends the cranium and intestines, when deprived of their contents, to be syringed with vitriolic ether.

Small animals, or the parts of large ones, are usually preserved by being kept in spirit of wine; for this purpose, it is observed by Leonhardi, that a little water and a fifth part of spirit of sal ammoniac should be added, which will preserve the colour and softness.

A method of preserving anatomical subjects in a very perfect manner, is the following. It is said to have been made use of by John Sheldon. He injects several parts of the body with strong spirit of wine, saturated with camphor, and mixed with a small portion of turpentine. The skin is prepared with finely pulverized alum, rubbed on with the hand. The intestines are taken out and covered with a varnish, composed of a mixture of camphor, and

common resin. All the internal parts of the body undergo the same operation, and are afterwards rubbed with alum. The body thus prepared is laid on a bed of calcined chalk to the thickness of one inch, in order to absorb all humidity, and is then placed in a double case of wood, the inner of which is of cedar. In this manner he has been able to preserve the body of a young woman for several years, which retains its form and appearance nearly as perfect as in life. Even the natural tint of the skin of the face is preserved, by a coloured injection impelled through the carotids to produce that effect.

Chaussier has discovered, that if the bodies of men or Chaussier. other animals be plunged for some time in a solution of corrosive sublimate, and then dried, they assume the consistency of wood, and the air produces no effect upon them afterward; and if the bodies be injected previously, they will retain the colour and appearances of life, and consequently form mummies more perfect than the *Ægyptian*.

It is well known, how disagreeable and very incon- Fourcroy. venient that putridity is to the anatomist, which often so soon takes place in bodies or their parts under dissection, and to Fourcroy it is, that we are indebted for a method by which these inconveniences may be prevented: it consists in sprinkling the parts with oxygenated muriatic acid. He informs us, the abdominal muscles of a subject for demonstration having been removed, and the cavity of the abdomen laid open, notwithstanding the contents were carefully removed, it was found to exhale a considerable putrefactive smell; care, however, being taken to wash the whole internal surface with the liquid oxygenated muriatic acid, the odour was immediately destroyed, and the students that had quitted the body soon resumed their situation without being afterwards incommoded; they also continued their dissection in the abdominal

cavity, and in the chest, which was also washed with the same, for a much longer time than usual without perceiving any degree of fetor. A mild and humid state of the air, during which the putrefaction of bodies is known to proceed very rapidly, produced little effect for the space of eight days, on the body sprinkled by the acid, whilst in the same period other bodies had acquired the highest degree of putrefaction. The muscles, the nerves, the vascular membranes, and all the other parts continued firm and without alteration.

This chemist therefore advises, that in bodies for dissection, the parts should be sprinkled as they are laid open. This method, which will preserve bodies for more than six weeks, taking care to repeat it from time to time, is easily practised, as a sponge dipped in the acid is slightly rubbed over the parts, taking care to avoid the vapour by turning the head aside.

He likewise advises the use of this acid for another purpose during dissection. One of the great difficulties in dissecting the soft and pulpy parts, as the brain, cerebellum, medulla oblongata, and spinal marrow, is the want of firmness in their structure, and the consequent yielding of their particles to any impression. This softness likewise renders them very liable to change by putrid decomposition, and they become oftentimes so putrid in a few hours, as to make it impossible to determine their structure, although these parts, to be well understood, require a long and attentive examination. It has been proposed to heat them a little above 45° of Reaumur, to give them a firmer consistence, and although the albuminous matter which forms their basis is susceptible of this density from the impression of heat, it is not sufficient for the anatomist, as the soft fibres of these organs are compressed together, and become less apparent after the operation. Fourcroy, therefore, thinks he has dis-

covered a more advantageous method. Having observed that all animal substances, especially the skin, membranes, &c. become firm and compact after maceration for some hours in liquid oxygenated muriatic acid, and that their fibres were made to approach each other in a remarkable manner; he steeped a human brain for eight hours in this liquid, and afterward plunged it once or twice in fresh water to wash off the acid, and found it's substance became firm, was readily cut, and it's tissue not disorganized by gentle pressure, as is generally the case with this organ. It also preserved it's whiteness and consistence for more than eight days, and did not become putrid in near the same time as in ordinary circumstances.

The utility of this property of the acid, in hardening and preserving animal substances, is likewise extended to the soft and almost mucous flesh of most fishes, and the glairy substance of worms, snails, &c., which is of great importance in the art of anatomy.

Having described the phenomena, and the circumstances attending *atmospheric* putrefaction, and the methods of preserving animal substances from it, an account of the decomposition they undergo, on exposure to other mediums, may be a means of throwing some light on the revolution the animal creation goes through in it's various metamorphoses.

2. *Terraneous putrefaction.*

The phenomena which take place when bodies are buried in the ground are different from those which follow on exposure to the air. It appears their destruction varies according to the nature of the soil. Sometimes bodies are found to have undergone a total decomposition after a very short interval, and at other times, as is the case with mummies, centuries are necessary entirely to destroy them. It is easy to conceive, according to Four-

2. Terra-
neous pu-
trification.

croy, that if the earth be very porous and movable, if the animal matter be buried at a small depth, the air, and especially the water, which can have no difficult access to it, will facilitate it's decomposition, whilst in opposite circumstances it must be much slower ; thus, for example, if the earth be dry, it will absorb the aqueous part of the bodies, exsiccate and convert them into mummies, as is the case in Egypt, where a sandy soil exposed to a burning sun gives them a hardness that defends them from destruction for ages. On the contrary, if the bodies be buried in argillaceous earth, which retains the water, the destruction is accelerated. In those cases where the decomposition takes place more or less slowly, the fluids and the solids become at last reduced almost to azot, carbonic acid, hydrogen, and alkaline gases. All these elastic fluids being filtered through the earth, escape and experience other vicissitudes ; but as the spontaneous decomposition of animal matters, especially when buried in large masses in the earth, affords some curious and singular results, it will be necessary to give a more detailed account of them, such as they have been collected by Fourcroy, in a memoir written on the bodies found in the churchyard of the Innocents at Paris.

Bodies in
the Inno-
cents at
Paris.

It appears that the earth of this churchyard had been surcharged for many ages with bodies delivered up to putrefaction in large masses, which in consequence might be supposed to have a different effect from that of other cemeteries, where each body has it's peculiar lot of ground, and where nature is able to separate it's elements with facility and promptitude. The calculations of some philosophers had indeed extended the total destruction of a body to about six years, from the observations made upon common burying places ; but these could not be applicable to the cemetery of a large city like Paris, in which many successive generations of it's inhabitants had

been buried for more than three ages ; for nothing indicated that the entire decomposition of a body might be prolonged beyond forty years, nor could it be suspected what a singular difference nature was able to present in the destruction of bodies buried in large quantity, and of those only isolated in the earth ; nor could it be known what might be the effects of an earth many yards deep, the stratum of which was incessantly exposed to putrid emanations, and saturated with animal effluvia, upon new bodies placed in it ; these, however, have been discovered by Fourcroy, forming an important addition to the history of animal decomposition or putrefaction.

The remains of the bodies buried in this churchyard were found in three different states, which appeared to depend on the time they had been inhumed, the places they occupied, and their disposition relatively to each other.

Found in
three different
states.

1. The oldest only offered to observation a few portions of scattered bones placed irregularly in the soil from having been often disturbed to give place to others, and in which nothing appeared except their difference from other human bones that had not been in the earth, and it was with respect to the soft parts including the teguments that the two following differences were observable.

2. Of the isolated bodies, the skin, muscles, tendons, and the aponeurosis, were dried, brittle, hard, of a more or less gray colour, and resembled the mummies in the catacombs at Rome, or in the cellar of the Cordeliers at Toulouse.

3. The third, and most curious state, was found to exist in the soft parts of the bodies that were accumulated in the common pits. These pits were above thirty feet in depth, twenty broad, and of the same width ; they were dug in the cemetery for the reception of the bodies of the poor, which were placed in close ranks, in coffins,

so that the whole pit was a mass of bodies separated only by the thin sides of the coffin, and each pit contained from 1000 to 1500 bodies. Three years were necessary to fill one of them, and they were opened again to receive other bodies not sooner than fifteen years, nor later than thirty years. The gravediggers had, however, been taught by experience, that this period was insufficient for the total decomposition of the body, whilst the alteration it underwent during the time was well known to them. This change likewise struck the observation of Fourcroy, in the very first pit he was present at when opened. It had been filled and closed about fifteen years. The sides of the coffins were found, and tinged of a yellow colour. On taking off the lids, the bodies appeared flat as if they had been pressed, and when the shroud was removed, the matter that surrounded the bones was in irregular masses of a soft ductile consistence, and grayish colour. On pressing this matter with the finger, it gave way and broke. It resembled in appearance common white cheese, and the print of the linen left upon it's surface heightened the resemblance. On rubbing this substance, it became soft. The gravediggers were accustomed to call it *fat*, from it's great similarity to that substance, but they only found it in bodies buried in mass, and never in the isolated ones. There was no infectious or very disagreeable odour perceived. This chemist examined many bodies of this kind, but all were not equally far advanced in this singular conversion, some of them had still portions of muscles remaining amongst these white fat masses, which were recognized by their more or less red colour and fibrous texture. In the bodies totally converted, there was no vestige of either skin, membrane, muscle, tendon, vessel, or nerve; the grayish white mass that covered all the bones appearing like cellular membrane, which, according to this chemist, might

Their curious conversion into a fat matter.

induce an opinion of the mucous part being the real basis of this singular matter. On examining further, it was found that all the viscera were likewise so changed as to leave scarcely any trace of them ; the abdominal cavity no longer existed, and it was in vain to seek in the greater number of bodies either for the situation or substance of the stomach, intestines, bladder, liver, kidneys, or womb; all were, to use the expression, melted down into this fatty matter. It was the same with the cavity of the thorax, it no longer existed. It's viscera were often entirely changed, and the greater part had disappeared, nothing remaining but some lumps of this white fat. He found this matter, which is the product of the decomposition of the viscera charged with blood and different humours, to differ from that on the external part of the body and bones, by being always of a more or less red or brown colour, and that the fat parts afford a much greater quantity than the others.

The face, in general, was no longer to be recognized; the mouth was disorganized, and without tongue or palate; the cartilages even of the nose partook likewise of the general alteration; the orbits, the ears, were equally changed. The skin, however, retained the hair, which appears to subsist the longest, and make the greatest resistance to every change, whilst the brain was always present, but converted like the other organs.

With respect to the modifications of this substance, it's consistence was not always the same; in bodies the latest changed, *i. e.* from three to five years, it was soft and very ductile, very light, and contained a large portion of water; in those which had been changed from thirty to forty years, it was more dry and brittle, it's foliated texture was much denser; and in some bodies where the soil was dry, portions of it were become semi-

transparent, and it's aspect, texture, and brittleness, very well imitated wax.

The epoch of it's formation has likewise a great influence on the nature of this substance; all that had been formed a long time was in general white, homogeneous, without any appearance of fibrous or foreign matter, and this was more particularly the case with the skin of the extremities. On the contrary, in bodies recently converted, it was not so pure; there were some portions of the muscular, tendinous, or ligamentous parts, the texture of which, though they were altered in colour, was still to be recognized; but these were more or less penetrated with fat matter, to be seen between the interstices of the fibres. Hence not only the fat parts, but the other parts are really converted into the same substance, although the first undergo the change much more easily and quickly.

Two varieties of it.

From the observations of Fourcroy, it appears, therefore, that amongst the modifications respecting the state of bodies converted into fat, two varieties may be distinguished; the one dry, friable, and brittle; the other soft, and ductile; to which may be added, that the first, which is oftener found in bodies placed near the surface, not only differed from the other by the water it had lost, but it had undergone a new change, and it had lost one of it's principles by volatility, so as no longer to be of the same nature as the other, as will appear.

This fat matter, in some of the bodies, was very beautiful, it's surface brilliant, and of the colour of gold and silver, and appeared covered over with a slight stratum of mica, whilst some points were of a red, orange, and carnation colour, and of extreme brilliancy, more particularly near the bones, which were themselves penetrated with it.

From the account of the sexton, it seems nearly three years are necessary for a body to become changed in the earth, and the successive alterations they undergo before they arrive at the state already mentioned, are the following: the inhumed bodies appear not to be sensibly changed in colour before seven or eight days, and this alteration first takes place in the lower belly, as is the case with those bodies not inhumed. The belly swells, and appears to be distended by the elastic fluids disengaged from the incipient decomposition, and this follows more or less early, according as the belly is more or less large and filled with fluids, the depth it is buried, and more particularly, according to the more or less warm temperature of the air. Hence, if all the circumstances favourable to this first degree of putrid decomposition be united, a very fat body, the abdomen of which is exposed to moisture by being buried near the surface, and the season warm, will become swelled in three or four days, whilst a meagre body, deeply inhumed, and in a cold season, will remain several weeks unchanged. It is a fact worthy of observation, that the state of the atmosphere during a storm has great influence in producing this swelling, and the expression of the gravedigger is that the belly *bloats* at the approach of storms; this distention increases until the parts are so extended and relaxed by putrefaction, as to burst with a sort of explosion, which happens near the umbilicus, and sometimes around the navel; from this wound runs a sanious, brownish fluid, of a very fetid odour, and at the same time a very mephitic elastic fluid is disengaged, the dangerous effects of which the gravediggers have learned to dread from experience. Multiplied experience likewise, which tradition has confirmed, has instructed them, that it is only at this period the miasmata disengaged from putrid bodies have any effect, from which real danger is to be expected. We are informed by this able chemist, that so strong is this

Progress of decomposition in isolated and accumulated bodies.

The danger attending them.

gas, that it several times happened when the pickaxe has accidentally struck upon the lower belly, an elastic fluid escaped, from which the person employed was suddenly struck down in asphyxy, and hence arises the dangers of the sexton; but for a further account of this misadventure, vide article *Miasmata*.

The distention and rupture of the lower belly equally takes place in bodies heaped together as in the pits, and those that are isolated; but the changes which succeed this first period of spontaneous decomposition are, as has been already mentioned, very different in each.

The isolated bodies being surrounded with a large quantity of moist earth are entirely destroyed, and prevented therefore from undergoing all the successive degrees of common putrefaction; this destruction is the more quick, the more humid the body is, and according as the heat or coldness of the season is accompanied with humidity. If, on the other hand, the isolated bodies are dry, or emaciated; if the earth in which they are placed is acid and void of humidity; if the atmosphere is dry, or if the rays of the sun falling on the surface favours and accelerates the evaporation; all these circumstances united exsiccate the bodies by absorbing or volatilizing the aqueous parts, and by contracting the solids, so as to give rise to those species of mummies before mentioned.

In the pits, every thing is different, the great mass of bodies heaped upon each other, and at a great depth, are not as the isolated ones are, exposed to the influence of external agents, or if at all, in a very inferior degree; hence the changes they are subject to depend on their own substance.

When the rupture of the lower belly has taken place, the abdominal putrefaction that caused it appears to have already disorganized the viscera of this cavity, the stomach and intestines no longer form a continued mem-

branous tube. Broken in many parts, and already dissolved into a putrid sanies, this process becomes more rapid and totally destroys the texture; the parenchyma of the liver, however, from its solidity perhaps, seems to resist this septic menstruum, the putrefaction does not advance to a complete destruction from the deficiency of humidity, and such undoubtedly is the cause of those fragments of fat that are found instead of all the abdominal viscera.

The putrefaction excited in the abdomen soon communicates with the thorax by dissolving the fibres of the diaphragm; hence the more or less complete destruction of the vessels, membranes, and all the soft parts of this cavity, every thing announcing that its disorganization goes on at the same time as the abdomen's, or at least very soon after; hence in this part only a few irregular masses of fat remain. The same disorganization takes place with more or less energy in all the muscular, tendinous, and ligamentous parts that surround the bones, according to their softness and the quantity of their aqueous parts; the conversion into this fat substance successively pervades every part; every thing that is membranous and more or less mucous is destroyed and disappears, and there is no longer any trace of vessels, nerves, or aponeurosis in those masses of fat that cover the bones of the extremities; all are converted into this substance.

Fourcroy, on examining the other cemeteries, found that the same alteration took place in the inhumed bodies as in that of the Innocents; hence the formation of this curious substance does not belong exclusively to the soil, but takes place perhaps universally where bodies are buried in large masses by the side of each other, and where, being less exposed to the action of those agents that operate in common external putrefaction, are only exposed to the reaction of their own component parts on each other.

To this may be added, that this chemist likewise found, on visiting a great number of burial places in Paris, that the change of bodies into mummies by exsiccation was much more common in a great number of soils than is generally supposed.

The conversion into fat arrests the putrefactive process.

The bodies converted into this substance in those pits that have been filled up for 40 years, prove, that once arrived at that state they are capable of being preserved a long time without being subject to intire destruction, whilst nature at the same time, who spares nothing, must certainly be in possession of some means of decomposing this new substance, and of reducing it again to it's elements. What became of it when formed, this celebrated chemist was desirous of finding out, but the most experienced and oldest grave diggers were not able to afford him the least satisfaction on this interesting point. Some facts however, appear to authorize a belief of his having discovered one of the processes by which it is detached from the bones, and decomposed.

It's final decomposition.

In some of the coffins that had been deranged from their horizontal to an oblique position from part of the earth having given way, the inferiour portion of the body was found reduced to the state of a skeleton, whilst the superior part still preserved it's masses of fat; hence a menstrual cause was looked for that had acted on the lower without touching the upper part.

On examination, this chemist found in the inferiour part of the coffins a brown and foetid fluid, the earth about them was likewise moist and penetrated with the same matter as the water in the coffins; these were only to be found, however, at the bottom of the pits, and in general the fat of all the bodies that occupied this region was the softest, the most changed, and the least in quantity. These phenomena indicated to him the action of rain water which had filtered itself through the earth,

was collected at the bottom of the pits, where it bathed that part of the bodies within it's reach, and was imbibed by the fat matter. This account was corroborated by the gravediggers, who observed, that after long and heavy rains the soil at the top of the pits is apt to sink for some inches. This proves the reason of the diminution in the mass of bodies, the fat or soluble part of which is by degrees taken up by the water, and distributed in more minute particles to the surrounding earth, and in which this chemist found the elements of this peculiar substance. Such is the progressive succession of the natural phenomena observed by Fourcroy in the changes bodies undergo in the earth; but he very properly adds, it is only an imperfect sketch of a great picture, to which future chemists must add the finishing touches.

To render it more perfect, and to know and describe, in all it's stages, the slow and gradual decomposition of dead bodies inhumed in the bosom of the earth, is a lamentable task; it is to be indefatigable for an age in the most sorrowful investigations, and to live amongst tombs, and breathe the noisome effluvia arising from them.

From the experiments which Fourcroy made on this fat matter, it appears that it is an ammoniacal soap formed of a *peculiar concrescible oil*, united in different proportions with ammonia; and that this soap likewise contains small quantities of the phosphates of ammonia and lime, which, however, do not enter the saponaceous combination, but are only interposed between it's particles; their quantity likewise varies in a singular manner.

With respect to the proportion of ammonia, it is almost impossible to ascertain how much the fat contains. It's proportion varies according to the time it has been taken out of the earth, as was proved by it's slow decomposition when exposed to the air, for the ammonia not being very adherent, an external heat above 15° is

sufficient in time to effect it's separation ; the proportion likewise probably varies at the period of it's formation in each body, which depends in particular on the nature of the body itself. This matter therefore is not to be regarded as always identic, and as containing the same principles in the same proportion. The state of each body, the epoch of it's burial, the situation, the height it occupies in the pit, the number of bodies, the disposition, the greater or less quantity of them, must have great effect on the difference in the quantities of the component parts of this soap. Likewise when it is exposed to the air on being taken from the pits, the proportion of it's principles will vary according to the place it is exposed in, the size of the pieces, and the temperature and dryness of the air. But the most essential point to know, is, that this soap continually tends to decomposition, that the ammonia is by degrees disengaged, and that at last the sebaceous matter which makes the basis of it is left intirely naked and in the form of a yellowish oily concretion, semitransparent, dry, brittle, and granular in it's fracture.

This fat is dissolved neither by cold nor boiling water, but it absorbs it with such activity, and adheres to it in such a manner, that it retains a great quantity which singularly augments it's volume. This adherence renders the water thick and viscous, and prevents it from passing through the pores of the filtering paper. On the addition of sulphuric acid, Fourcroy found, that a gas, or rather an odorous effluvium was extricated, of an insupportable foetidity ; it was very fixed, and infected the laboratory for several days afterwards, although the windows were often kept open. This gas, therefore, is very different from that of common fat. By the nitric acid azot gas was only extricated, when the fat contained the remains of fibres ; when pure it affords carbonic acid gas.

This oil, or concrete oily matter, appears to be different from all others hitherto discovered, and is a new product arising from the decomposition of bodies under certain circumstances, which had escaped the attention of chemists. For a particular account of it *vide animal oils*. Is a new production.

A similar decomposition appears to have taken place in a liver, which although it had been exposed to the external air, seems, by having become exsiccated, to have escaped the total decomposition which is the consequence of such exposure. In the beginning of the year 1785 a piece of human liver was examined by Fourcroy, which he received from Poulletier de la Salle; this liver had been exposed for more than ten years to the open air suspended by a packthread string. It had at first given out a disagreeable putrid odour, had been in part destroyed by the larvæ of several insects, but without being totally dissolved by putrefaction, was become reduced by degrees to a gray friable matter, and for three or four years appeared not to have undergone any new alteration. From the first aspect of this piece of liver it might have been mistaken for an earthy substance, analogous to that called mineral agaric; on a closer examination however, some portions of dried membranes of a brown colour were very evident, together with some vascular parts equally dried. When rubbed between the fingers it was greasy and soft to the touch, resembling soap. From the experiments this chemist made upon it, although he was limited as to the quantity, it appears to be analogous to what he found in the remains of the bodies above mentioned, inhumed in the cemetery at Paris, or in other words, that it was a concrete oil resembling spermaceti. A similar conversion in a human liver.

1st. A small portion of it placed on a hot coal at first became soft, and exhaled an odour similar to burnt fat; it then melted, swelled, and became black; on incinera-

tion, the light carbonaceous matter was converted into a white ash.

2d. On distillation, half an ounce afforded a few drops of a white aqueous insipid fluid, which was soon succeeded by a thicker fluid, and an oily white smoke, which was condensed in the neck of the retort into a white concrete matter; afterwards a very putrid disagreeable odour was perceived, the concrete oil became of a rust colour; carbonated hydrogenous gas was obtained. A great part of the liver had passed without decomposition. The concrete oil in the neck of the retort had a lamellated and crystalline appearance. The products showed no signs of either an acid or an alkali.

3d. Two ounces of hot water dissolved a little out of one drachm. The solution was white and opaque, had a slight soapy odour, and sensibly changed the syrup of violets green; the undissolved portion melted by heat, crystallized on cooling, had a fat odour, and inflamed; this slight solubility showed it consisted of an oily concrete matter.

4th. A drachm of it triturated with half an ounce of the caustic lye of potash produced a slight odour of ammonia; boiled for half an hour and filtered, the solution, on cooling, became concrete, of a brown colour, and dissolved in every proportion in boiling distilled water, leaving no residuum. It appeared that the whole of the liver had been dissolved by the alkali, even its membranous and fibrous parts. This solution in water frothed very strongly on agitation, and on cooling deposited some white light flakes. Limewater, acid, and earthy neutral salts precipitated them more abundantly. Hence the alkali had dissolved a fat oily matter, and formed with it an homogeneous soap.

5th. Two ounces of alcohol with one drachm of the

levigated liver exposed to a gentle heat dissolved about half of it, and the residuum treated twice more with alcohol, there only remained 20 grains undissolved, formed of membranes and vessels that had escaped the action of the alcohol. On the addition of water, a substance was precipitated in the form of white flakes, which was a concrete oil resembling spermaceti, for which *vide animal oils*.

6th. The oil expressed from the liver after exposure to a heat of 68° of Reaumur, in water, and rendered concrete by cold, had nearly all the properties of that dissolved in alcohol, except, first, it had more colour, and was more fetid. Second, it contained a portion of soap, which the water had separated from the alcoholic solution in the first instance.

7th. The portion of soapy matter regarded as an extract in the first experiment, excited the attention of this chemist. It was certain that water as well as alcohol extracted it from the dried liver; but there was too little of the liver left to make any experiments upon to find out the nature of this soap. It appeared to be formed of the same concrescible oil as that extracted by expression, &c. It was even conjectured by this chemist, that before the complete alteration of the liver, and its total conversion into a concrete oily substance, this oil was at first in a soapy state intirely united to soda and ammonia, since it appeared that the portion of ammoniacal soap still remaining in this piece of liver proved, by the ammoniacal odour disengaged by quicklime, and its insolubility in water, to be more abundant in that portion of the liver that was deeper and less exposed to the air than that examined. Such are the experiments he made on this substance.

Hence it appears, that this concrete oily matter found in the bodies in the churchyard at Paris, and in the hu-

man liver, is the constant product of a slow decomposition, of a long putrefaction.

Brain simi-
larly con-
verted.

Another instance of a similar conversion, and in consequence the long preservation of a certain organ of the body, is the brain. The propensity of the brain to corrupt before most other parts of the body is well known to dissectors, and yet under certain circumstances, it is the last viscus destroyed by putrefaction; and this singular faculty of resisting destruction has been long ago observed. Fabricius de Hilden relates, after George Faber, an example of this kind; the body had been buried 50 years, but the brain, he informs us, had undergone no sensible alteration; it was white, ran like an oily matter, yet exhaled no noisome smell. According to Theophilus Raynaud, a brain was found at Avignon equally soft and of the same nature, whilst the body had been buried a great number of years. Peter Borell gives an account of the brains of some massacred people, whose bodies had been thrown into the wells of the Dominicans, at Cesires, that after 80 years were still soft and without stench. A memorable example of the same kind was found in the celebrated catacombs of Kiovie, on the banks of the Boristhenes, a description of which we owe to Herbinus. This author asserts, that the crania of a great number of mummies perfectly preserved in those places, are filled with a fat and oily matter that runs from them. The resemblance of this oily matter with that already mentioned by Fourcroy, is a proof of the observation having been made before, although no experiments had been made upon it.

3. Aqueous
putrefac-
tion.

3. *Aqueous putrefaction.* It also appears, that all animal substances, except the bones, nails, and hair, are equally susceptible of being converted into this fatty matter on being exposed to the effects of water. Rouelle and d'Arcet, in 1777, had observed a phenome-

non of this kind in a dog, found under water in the Seine, all the flesh of which was converted into this substance. This fact has been since confirmed by the experiments of Gibbs; for having placed at different times a couple of cows and two horses in water, or in a running stream, the flesh was converted into a substance resembling spermaceti. The cow was placed in a situation where the water could have access twice a day; over it some loose earth was thrown: after it had remained some time, on pushing a stick through the earth to the body, a prodigious quantity of extremely offensive air arose, and in one year and a half the whole muscular part was changed into this white concrete matter. The water over the animals, and for some distance around them, is covered with a beautiful pellicle, which is white in general; sometimes it refracts the sun's rays, producing the prismatic colours. He likewise exposed a piece of beef in a box pierced with holes to the current, and found it had undergone a similar transformation in one month after.

Conversion
of a dog.

Cow.

Horse.

Fish may also be changed, and it appears this concrete matter is formed in the body of an animal. Gibbs observed, on seeing a body opened where there was a great collection of water in the cavity of the thorax, that the surface of the lungs was covered with a whitish crust, which he attributes to some combination that had taken place between the lungs or pleura and the serous fluid effused, similar to that between flesh and water. Dr. Cleghorn also mentions a similar circumstance, in speaking of abscesses formed in the lungs. These abscesses had sometimes emptied themselves into the cavity of the thorax, so that the lungs floated in purulent serum, and their external membrane and pleura were greatly thickened, and found to be converted into a whitish crust, like melted tallow grown cold.

Conversion
also of fish.

Surface of
the lungs.

The only difference on comparing this substance with

that formed in the cemeteries of Paris was, that where large masses of bodies are inhumed the concrete oily matter or spermaceti appears in the form of a soap, whilst in those immersed in water the ammonia is not formed, or if formed, is dissolved and carried away by the fluid in proportion as it takes place.

Human
fœtus.

The human fœtus has been likewise found to be converted into a fatty substance from remaining in the liquor amnii, and there is a similar substance to be met with in that liquid which is deposited upon certain parts of the fœtus, called by Buniva and Vauquelin the caseous matter, it is supposed to be a conversion of the albumen. *Vide* article Liquor Amnii.

And the
caseous
matter
found upon
it.

This conversion of animal substances into an oily matter resembling spermaceti may be produced artificially, by means of the nitric acid; for an account of which, *vide* *Animal oils*.

It appears, therefore, to be this state that all animal matters pass into under certain circumstances, *i. e.* when the external air is prevented from acting upon them so as to have no influence on their decomposition, either by their being heaped together in large masses, by partial exsiccation, by water, or by nitric acid.

Explan-
ation.

To account for the changes animal substances undergo on being converted either spontaneously or artificially, into this singular matter, which is a more simple state of composition, the quantity and proportion of the primitive materials of the different animal substances susceptible of it must be previously known, and scarcely nothing has yet been done in chemistry to afford this knowledge. The component parts of animal matters may, however, be reduced, as before observed, to oxygen, carbon, hydrogen, and azot, for the sulphur, phosphorus, lime, and soda, contribute nothing, according to Fourcroy, to their formation, if the phosphat of lime be excepted, which

constitutes bones, and which has no influence on the above change. According to modern chemistry, the soft animal matters, the skin, muscles, ligaments, &c. may be regarded as different kinds of carbonated oxyd of hydrogen and azot, and these oxyds, more complicated than those of vegetable substances, tend even more on that account incessantly to alteration; the equilibrium of their combination is easily destroyed, and this is brought about by the least changes in the temperature and humidity that surround them. These incontestible principles being laid down, the decomposition of these matters and the formation of the fat may be explained in the following manner.

The carbon escapes in great quantity in the form of carbonic acid gas, either by reacting on the aqueous part, or by simply absorbing the oxygen they contain. This volatilization of the carbon with the oxygen is the principal cause of the considerable loss animal substances undergo in their conversion into *fat*, for this last only forms the tenth or twelfth part of every body. The azot, a principle so abundant in these substances, combines with the hydrogen, and forms ammonia, one part of which is disengaged in vapours, whilst the other part remains fixed in the fat; the residuum of these substances thus deprived of a great part of their carbon, of their oxygen, and of all their azot, which last no longer exists in well formed fat, is found to contain a much larger portion of hydrogen, and it is ^{this} carbonated and slightly oxydated hydrogen that constitutes this peculiar concrete oily matter, or adipo-wax, as it has been called, the union of which with the ammonia forms the animal soap called *fat*. There only remains to determine whether it is the oxygen contained in the animal oxyd, or that which forms a constituent part of the water, that serves to compose this oxyd, in order to bring about the decomposition: and to accomplish this, two facts are wanting, viz. the exact proportion of

the animal oxyd, and that of the fat at the moment it is formed, and which further experiments must provide, although Fourcroy seems to be of opinion, that from the considerable proportion of hydrogen existing, whether in the ammonia formed or in the adipo-wax, it might give reason to suppose that the decomposition of the water is necessary to this spontaneous operation.

Miasmata,
the source
of infection.

Having given an account of the different species of putrefaction, it will be necessary, before concluding the subject, to take a view of one of it's productions, which, from the dangerous tendency or fatality of it's nature, has at various periods of time spread alarm and terror in all ages, and almost in all countries; this is the putrid matter which is the source of infection.

Amongst the evils to which the living body is exposed, the most dangerous perhaps are to be met with when the atmosphere we breathe is rendered pernicious by the generation of those destructive putrid exhalations which produce diseases, commonly called pestilential; and as these causes are too subtle to be discovered by any of our senses, and are only made known by fatal experience, it is from chemistry alone we can hope for relief, and by investigating the nature of such causes, collect means in order to prevent, mitigate, or destroy them.

But little
understood.

Perhaps no subject is less understood; it may be said to be involved in impenetrable darkness; while other subjects of inquiry have, in the progress of human reason, at least been attempted to be investigated, the remote cause of infection has remained a subject of doubt, a dismal something upon which scarcely a conjecture has been made, the origin of which no one durst hazard to investigate, and of which the operations appear to be capricious, multifarious and unaccountable.

Their pro-
duction.

It is well known, that during the spontaneous decomposition of vegetable, vegeto-animal, but more particularly

of animal substances, a gaseous invisible matter (as before observed) is extricated ; and this is capable of acting more or less powerfully on the living animal body, and of producing different degrees of disease, from the common intermittent or ague, to the most terrible of all disorders the plague, and when this vapour is in it's most concentrated state, it's poison is so deleterious as to produce immediate death. This poisonous effluvium is called *miasma*, or perhaps more properly, *miasmata*. It is found to exist in low marshy and swampy grounds, in and about the environs of cemeteries in which numerous bodies have been inhumed, and wherever large quantities of vegetable, or vegeto-animal, or animal matters are exposed to the open air under a hot sun, so that they may attain their highest degree of putrefaction. It differs however in it's virulence ; thus in the northern climates where the process of putrefaction is very slow from the accessories being moderate, the diseases miasmata produce are generally agues, and they seldom extend beyond dysentery ; but in the eastern parts, as in Bengal, on both sides of the Ganges, in Louisiana, overflowed by the Mississippi, and in Egypt, covered annually by the Nile, when the waters retire and leave behind them the mud and slime, the great heat of the sun acting with unremitting force upon the relics which teem with myriads of animal beings, the miasmata produced are so virulent, as to give rise to the most dreadful pestilence, and in the most deadly form.

The term *infection* has been generally employed as synonymous with *contagion*, and often with *miasmata* ; but several authors of late, particularly Dr. Baily, an eminent physician of New York, who first made the distinction, have employed these terms to express different meanings ; and Webster has adopted the same distinction. They affirm, that the circumstances that characterize *infection*

Distinction
made be-
tween in-
fection and
contagion.

are, that it produces epidemics that extend over immense tracts of country ; that it's diseases are not easily communicated out of the pestilential atmosphere, and that it is mitigated, suspended or destroyed by cold. On the contrary, the principal features of *contagion*, are, that it produces diseases, but not to any great extent, that they propagate themselves, and that it is favoured by cold. They assert, that the fever which owes it's origin to certain connections with the putrefaction of dead vegetable and animal matters, shows no disposition to propagate itself, whilst the fever arising from a connection with the living human body in a certain diseased state, as in measles, smallpox, &c. multiplies with great activity. The one is peculiar to particular states of the climate, exists generally in the autumnal months, in hot climates, and but rarely in cold, although it has appeared from general changes in the climate, even in the more northern regions ; the other is not peculiar to season or climate, appears oftener in winter than in summer, and in temperate than in hot climates ; but as it depends upon adventitious causes, it sometimes commits ravages in summer, and has even appeared in the torrid zone ; the one originates from natural sources, the other from artificial ones ; such is the general hypothesis of this distinction, the conclusion of which is, that infectious diseases arising from miasmata are not communicated, whilst contagious diseases are.

Ancient
and modern
opinions
on the con-
tagion of
pestilential
diseases.

A variety of authors have contended for and against the contagion of pestilential diseases ; among the ancients, Galen, Aristotle, Thucydides, Seneca, Forestus, Prosper Alpinus, Diemerbroeck, Sydenham, and others, contend, that the plague as well as other pestilential diseases is contagious ; whilst Procopius, and those who oppose the doctrine of contagion, not only produce as authority, the silence of Hippocrates, Avicenna, and

other Arabian physicians, on the subject, but they affirm, that if the plague was a contagious disease, it would *always* infect those who communicated with the diseased.

Amongst the moderns, besides the two already mentioned, Dr. Smith, of America, and Dr. Maclean, have supported the same opinion. The latter, in a small treatise, has attempted to prove that the plague, dysentery, and other epidemics, are never propagated by contagion, for only a very small portion of those that have been exposed to the action of the effluvia of the deceased are ever affected by the distemper; he concludes those diseases only to be contagious which must necessarily act and communicate the disease within a certain distance, as the smallpox, measles, and which can only be received once by the same person; whilst the others, which may affect a person several times during his life, are caused by certain states or vicissitudes of the atmosphere only. He affirms, that the existence of contagion in the plague, dysentery, and fevers, has been uniformly taken for granted, not only without proof, but even contrary to the evidence of numerous and convincing facts.

Although these and several other physicians of eminence, particularly Dr. Rush, of Philadelphia, whose opportunities of observing the yellow fever, or plague, of America, have been very great, are of opinion, that pestilential diseases arising from miasmata are not contagious; yet as such opinions may as yet be looked upon as conjectural, without any direct, explicit, and perfectly deciding facts, to place such opinions beyond the reach of all doubt and controversy, it would be highly improper in the present state of knowledge on this subject, for either the magistrate or the physician of a board of health to divest themselves of the least precaution, either by putting an end to quarantine, or by not applying to every other

means that might place the safety and welfare of their fellow citizens beyond every the slightest suspicion and fear of such terrible calamities.

Among the numerous opinions given respecting the causes of pestilential diseases, whilst some have even denied the existence of a putrid cause, others have been so convinced of it's presence as to describe even it's peculiar smell. Those who have had infectious air fresh in their nostrils affirm, it is easily distinguished from all other known odours; but the different accounts they give of it may afford some reason to suspect them of error. Some call it an earthy smell, very disagreeable, that it in some measure affects the organ of taste, even extending into the stomach; others have compared it to the vapours issuing from a newly opened grave, but without the cadaverous stench; others think it resembles the effluvia of rotten straw; and others again are of opinion it is like the exhalations from the confluent smallpox at the turn of the pustules. The gravediggers mentioned by Fourcroy spoke of the odour from the bursting of the lower belly, in a state of great putridity, to be a horrible stench; and whenever they are exposed by an unfortunate chance to bodies in the earth, in this dangerous state, so great is it's poisonous activity, that if near, they are immediately struck with asphyxy; if at some distance, it only gives them a slight vertigo, a disagreeable sensation of fainting, or of nausea, which continues several hours, followed by loss of appetite, weakness, and tremours; hence arise those diseases which people are subject to who live in the neighbourhood of large cemeteries, a great number of whom have their countenances pale and wan, with other symptoms announcing the action of a slow poison. From the circumstances, however, in which this poison is extricated, it is perhaps, never admitted to the organ of

smell in it's pure form, but generally accompanied by some other gaseous and disagreeable emanation, that may have given rise to the different opinions of it's odour.

With respect to the manner in which contagion is communicated, Dr. Carinichael Smith is of opinion, that it is not only from a direct communication with the sick that contagious fevers are propagated, but that unfortunately the persons and clothes of those who remain long in a contagious atmosphere, and the excretions of the sick, are capable (even when conveyed to a great distance, or preserved for a length of time) of producing the same mischief as an immediate communication with the sick themselves, and that the jail distemper and putrid contagion are thus frequently conveyed cannot, he thinks, be denied. Indeed, wherever a vapour can be distinguished by the smell, we have the demonstration of our senses, for what a length of time, not only clothes but furniture, and even the boards and walls of houses will retain it; therefore, in respect to the jail or hospital fever, it may be safely affirmed, that it not only attacks those immediately exposed to the original atmosphere, but that this contagion may be certainly communicated by the clothes of those that have been any length of time confined in it; and what is more surprising, even when the persons themselves are not affected. Indeed, the dread of these terrible diseases may have probably magnified the danger beyond reality, and the risk of propagating the contagion may not be so great as is supposed; physicians, and even apothecaries not being so long exposed to this atmosphere as to be in great danger of conveying the contagion elsewhere, yet the persons, and especially the clothes of nurses and assistants, who are constantly confined amongst the sick, are certainly capable, according to Dr. Smyth, of communicating the disease; but he adds, that however paradoxical it may appear, he never observed that the

sick propagated the disease so readily as the bodies and clothes of those, who, though well, had been long confined in the original atmosphere. He is of opinion, that unless where contagion is very powerful, it is seldom propagated in the open air, and he knew only of one instance of this, at the prison of Winchester. He thinks there is but little risk of receiving contagion from the dissection of dead bodies, unless when the operator happens to cut himself.

The persons most susceptible of this contagion, Dr. Smyth asserts, are young persons, particularly if they come directly from a pure air into the infected atmosphere, those whose minds are oppressed with fear or anxiety, or who have been weakened by previous illness; even those who have been fatigued, or are fasting, receive it more readily than others whose strength has not been impaired, or which has been again recruited with food. A moist atmosphere is also more favourable to the communication of contagion than a dry one, and a contagious person becomes greatly more so, if his clothes are wet, and his body heated by exercise so as to be in a state of perspiration. It has likewise been remarked, that persons who have issues are seldom affected by contagion.

Putrid matter, in whatever way generated, if in sufficient quantity, has always some deleterious effect acting as a poison upon the body; and this effect takes place whether the putrid matter be generated in the body, taken into the stomach, or into the blood by means of a wound. It is true, the human stomach, and still more remarkably, the organs of digestion of certain animals, have the power of counteracting the septic tendency; but this power, at least in the human stomach, is very limited, and when any matter, whether generated in the body or introduced from without, has acquired a degree of putridity beyond this, it occasions nausea, vomiting, purg-

ing, great oppression at the region of the stomach, and often a fever, either of the intermittent, remittent, or more continued kind. Putrid matter directly introduced into the system by means of a wound causes swelling, and inflammation of the lymphatic glands, often terminating suddenly in gangrene, along with the symptoms of a fever, greatly resembling the hospital or jail fever; the same prostration of strength, tremors, anxiety, headach, and delirium, and all the symptoms of a bad putrid fever, as petechiæ, hemorrhage, indicating a certain decomposition of the blood. The fevers that arise from exposure to putrid vapour or contagion assume a variety of types and forms, according to the degree of putridity, season of the year, constitution of the patient, &c.; but they as well as the preceding will be found to have many symptoms in common, and similar to the jail and hospital fever; and in reality, all the fevers of this class, from the slightest vernal intermittent to the true plague, are, as Dr. Smyth observes, only different shades or varieties of the same disease, and productions of one common cause, viz. putrefaction.

What that subtle or powerful vapour, or whatever else it may be, is that arises during the putrefactive process, and acts in the form of such a powerful poison, is unknown. Various, however, have been the opinions on the cause of pestilential fevers.

On extending our investigation towards antiquity respecting the origin of pestilential diseases, we shall find that superstition was the first to account for them, by ascribing pestilence to the immediate exercise of Divine Power. It was supposed that it was one of the judgments that God inflicted on mankind in his wrath, to punish them for their iniquities; thus when ^{David} Daniel was summoned to receive his punishment for numbering the

Ancient
and modern
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pestilence.

Scripture.

children of Israel, having been permitted to make choice of the three greatest calamities, he preferred, for a pious reason, pestilence to either famine or the sword; and 70000 of his subjects perished. "I will smite the inhabitants of this city both man and beast, they shall die with great pestilence." 2 Sam. 24. Jerem. ch. 21.

Homer.

In perhaps the oldest historical account of mankind, after the Bible, we are informed by Homer, that a plague raged during the siege of Troy, and pestilence is ascribed by the poet to extreme heat under the influence of the dog-star, and also to vapours.

"As vapours blown by Auster's sultry breath,

"Pregnant with plagues, and shedding seeds of death,

"Beneath the rage of burning Sirius rise."

POPE'S HOM. II. b. 5. 1058.

Hippocrates

Hippocrates attributes pestilential diseases to putrid air, which infects all animals that breathe in it. "First," says he, "I will begin with the most common febrile disease, which in some measure accompanies all diseases; for there are two sorts of fevers, one that is promiscuous, and common to all, called the plague; the other, by reason of unhealthy diet, is peculiar only to such as use that diet; but of both these kinds of fevers the *air is the sole author and cause*; the common fever or plague therefore happens to all, because all breathe the same air; and it is certain, that the same air being mingled in similar bodies must beget the like fevers." On demanding why infectious distempers seize not all animals alike, he answers, that when the air is filled with such filth and pollutions as are noxious to human nature, men only fall sick, but when it is hurtful to any of the other species of animals the disease seizes that species only. Hippocrates, however, seems to have been aware that there was something else necessary, for he speaks of *to theios* or some divine

principle in the air, which has been supposed to mean an epidemic constitution, arising from changes in the atmosphere produced by unknown causes.

According to the observations of Aristotle, pestilence Aristotle. may owe it's cause to a hot and dry south wind.

Galen, who lived at Rome in the reign of Marcus An- Galen. toninus, whilst a raging plague was desolating that city, is of opinion, that Hippocrates was mistaken in ascribing the cause of epidemic diseases to the air only, and observes, that pestilential fevers sometimes proceed from a great abundance of humours, whenever these have acquired from the ambient air the least tendency to corruption. He attributes also these diseases not only to the air, but to unwholesome food and vitiated waters.

Ammianus Marcellinus mentions a plague in the city Marcelli- of Amida, in Persia, when besieged by Sapor, about the nus. middle of the fourth century; it arose from the corruption of numerous dead bodies which lay unburied in the streets. He then proceeds to give the opinions of others on the subject, as follows: "Philosophers and eminent physicians have taught, that pestilence is produced by excess of heat or cold, of drought or moisture. Hence those that live near wet and marshy places are subject to coughs, diseases of the eyes, &c. Those, on the other hand, that reside where the heat is great, are troubled with febrile complaints, and in proportion as the matter of fire is more active, drought is more rapid in destroying life. Others are of opinion, that air, like water, vitiated by the effluvia of dead bodies, or similar substances, is deprived of it's salubrity, or at least, that a sudden change of air will produce the more slight complaints. Some also affirm, that the air, rendered gross by a denser vapour from the earth, closing the pores of the body, and checking perspiration, becomes fatal to the lives of others, for which reason those animals which are continually

bending towards the earth are the first victims to pestilence, as Homer testifies, and which is proved by many examples during the prevalence of pestilential diseases."

Ætius.

About the close of the fifth century, Ætius, who was an eminent physician, has compiled the opinions of his predecessors on epidemic diseases. "Those are called so," says he, "which originate from a common cause, as bad food, or water, immoderate grief, or want of customary exercise, hunger, or repletion, especially when abundance succeeds extreme want. But the nature of the country often causes epidemic diseases; the air we breathe being vitiated by the evaporation from putrid substances, such as multitudes of dead bodies after battles, marshes or stagnant water in the vicinity, which emit poisonous and fetid vapours. This cause is in continual operation."

Prosper Alpinus.

The Greeks called those diseases that operated universally *επιδημικοι*, and if at the same time they were very destructive, they had the name of a plague, by the Greeks, *λοιμος*, by the Latins, *pestis*, à *pascendo* or *pestilentia*, according to Isidorus, quasi *pastulentia*, quòd veluti incendium depascit, because it consumes and devours like a burning flame. But since, although at what time is difficult to say, a difference has taken place between *pestis* and *pestilentia*. It is, however, found in the works of Prosper Alpinus, a Venetian physician, who wrote about the close of the 16th century. This author maintains, that pestilential fevers are occasioned by local causes, as vitiated air, and by peculiarities of season, as extreme heat and humidity; but he asserts, that the plague in Egypt rarely proceeds from corrupted air, and never except after an unusual flowing of the Nile, and concludes, it is usually imported.

Diemerbroeck.

An eminent Dutch physician of the last century, Diemerbroeck, assigns three causes of the *pestis* or true plague. 1. The just anger of Heaven, provoked by ex-

halations from the finks of our fins and abominable deeds.

2. A most malignant, poisonous and deadly pestilent germe, like a subtle ferment or leaven, sent from Heaven in a very small quantity, diffusing itself through the air like a subtle gas, and rendering it impure. This gas, he supposes, spreads over many regions, and impresses, by it's numerous particles on the air, an infection like poison, which affects people.

He maintains the distinction mentioned by the last author, and supposes, that pestilentialia is produced by exhalations and intemperate seasons; whilst the plague, he contends, cannot be occasioned by those causes, though they may assist the germe or general cause.

According to Van Helmont, a Flemish writer of the last century, ^{but one} the plague cannot be ascribed to the unseasonable changes of times, nor to putrefaction; but that it's poison is a secret, that the matter of that disease is a wild spirit tinged with poison, exhaling from a diseased person, or drawn inwards from a gas of the earth, putrefied by continuance, and receiving internally an appropriate ferment, and by degrees attaining a pestilential poison in us. The remote, crude, and first occasional matter of the pestilence, is an air putrefied through continuance, or rather a heavy putrefied gas, which putrefaction of the air hath not the 8200th part of it's feminal body. When we compare this unintelligible explanation of this alchemist with the ancient method of ascribing the cause of pestilential diseases to the extravagant system of judicial astrology, the latter is by far the most satisfactory; both of them perhaps equally unphilosophical. The author, however, contends against a more ancient superstition, that the plague is not sent down from Heaven, but that popular plagues draw their first occasional matter from an earthquake, and from the consequences of camps and sieges.

Hodges.

Hodges, who wrote a treatise on the great plague in London in 1665, observes, that the air suffers some essential alteration which is necessary to favour the propagation of pestilence. The nitro-aerial principle, which causes or invigorates animal and vegetable life, sometimes becomes imperfect, degenerate or corrupt, being tainted with something pernicious to vitality. He calls it poisonous, and observes that it proves injurious to trees and cattle, as well as to man. He supposes the corrupting principle to be a subtle aura, or vapour, extricated from the bowels of the earth.

Van Swieten.

According to Van Swieten, the cause of epidemics is in the hidden qualities of the air, and is inexplicable.

Sydenham.

Sydenham agrees with Diemerbroeck, and Van Swieten, in ascribing pestilence to occult qualities in the air. Of the same opinion is Fernelius, Sennat, and Stenkius.

Mead.

Mead ascribes the plague to the putrefaction of animal substances and unseasonable moistures, heats, and want of winds; and affirms, that no kind of putrefaction in European countries is ever heightened to a degree capable of producing the true plague. He is surprised that authors should have recourse for an explanation of the causes to hidden qualities, such as malignant influences of the heavens, arsenical, bituminous, or other mineral effluvia, with the like imaginary or uncertain agents. He assigns three causes. 1. Diseased persons. 2. Goods transported from infected places. 3. A corrupted state of air. He does not, however, deny all latent disorders in the air, but considers them as secondary causes only, increasing and promoting the disease when once bred, and thinks infection to be the means of its propagation. In this he differs greatly from Diemerbroeck, who utterly denies that the disease is originally derived

from infection, although he agrees that it may be afterwards communicated from person to person by contact, or near approach. Diemerbroeck also maintains the latent qualities of the air to be the *principal* cause of the plague, or cause, *sine qua non*. Mead says, the plague is never originally bred with us, but always brought accidentally from abroad.

Mackenzie, who gave an account of the plague in Constantinople, supposes the disease to proceed from venomous molecu^{læ}, lodged in wool, cotton, hair, leather, and skins, in houses not well cleansed after pestilence. He thinks the air no otherwise concerned in producing the disease, than as a vehicle to convey the venomous particles from one body to another. Mackenzie.

The idea of Dr. Chandler greatly resembles that of Dr. Mackenzie, with respect to the origin of plague. He says it might be perhaps truly defined, 'a disease arising from certain animalculæ, probably invisible, which burrow and form their nidus in the human body. They always subsist in places suited to their nature. The species imported from Smyrna are commonly destroyed by intense heat. The pores of the skin opened by the weather, readily admit them. Chandler.

Gibbon the historian asserts, that the plague arises from hot, damp, stagnant air. Gibbon.

The Abbe Fourmont, that it originates from famine. Fourmont.

Dr. Mitchill, that the gaseous oxyd of azot or nitrogen is the matter of contagion; this is the dephlogisticated nitrous air, discovered by Priestley, it supports flame and extinguishes life. Dr. Mitchill.

It might have been expected that in descending to modern times, a more satisfactory account of the poisonous matter, whose action has been so very inimical to the human species, would have been given by physicians, but it appears, that no method has yet been found

out to render this invisible agent pervious to the senses, and that every thing respecting it hitherto has been either fable or conjecture. If, however, this terrible enemy has escaped the investigation of the philosopher, means have been employed to render the poison ineffectual, and to discover by chemical reagents what are the most effectual substances to counteract it's effects, either by decomposition, or chemical union.

Ancient
use of fu-
migations,
descending
to modern
times.

Hippocrates, we are informed, in order to destroy the pestilential particles of the air, made use of scented wood, which he caused to be burned in piles placed at the corners of the streets, but the remedy appears to have been equally as inefficacious as the smoking of tobacco, the thieves vinegar, with the rest of the numerous nostrums and amulets that have succeeded each other at different times. It is readily conceived why fumigations, and substances yielding strong odours, were first employed for this purpose. The plague, and other diseases, attended with great mortality in ancient times, being considered by the superstitious world, as judgments sent by the hand of divine vengeance, to scourge the human race for their sins, as before observed, sacrifices and expiations were made to the gods, to deprecate their wrath, and atone for the guilt of mankind. Sweet smelling herbs and flowers, and aromatic gums, as myrrh and frankincense, were therefore burnt during these ceremonies; and as the whole were of an agreeable odour, and overpowered the offensive effluvia of diseased or corrupted bodies, it was natural for these ignorant people to believe, that such fumes, by destroying the smell, destroyed likewise the polluted effluvia. Another circumstance observed by Dr. Trotter might have given rise to similar means. It was believed that the pestilential diseases were the offspring of putrid and of putrefying animal and vegetable substances, and these substances

they saw became the nidus and the nourishment of numerous young insects; whence they concluded, that their generation was spontaneous. To destroy these animalculæ, which in hot countries increase in such numbers, and which now on the wing they considered as polluting the atmosphere, brimstone and fire would soon be resorted to, as it was known, that no animal could approach their conflagration, so that every article that yielded either agreeable odours or pungent vapours was employed; hence the hyssop of the wall, the cedar of Lebanon, the camphire of Engedi, spices and the pitch of Norway, and the tobacco of Virginia, swell the antipestilential catalogue; and the fumigating substances have been handed down from the Jews, the Greeks, and the Romans, through the Arabian physicians and the dark ages of Europe to the moderns, and have maintained their reputation and character, amidst all the vicissitudes of human opinions, and the fleeting duration of medical theories. Nobody, till lately, has questioned a practice sanctioned by the authority of antiquity, and the universal suffrage of modern physicians, until the beautiful discoveries of pneumatic chemistry, which explained the nature and composition of elastic fluids, invited the chemical philosopher to apply his new acquired knowledge to the detection of the causes of pestilential diseases, and to find out the best and most suitable prophylactics against them.

Until a knowledge of the different airs that compose our atmosphere, and the various gases that arise from spontaneous or artificial decomposition, began to prepare the chemist for future investigation, little could be expected from any other branch of philosophy, but, no sooner did the experiments of Black, Cavendish, Priestley, Lavoisier, and Berthollet, afford a light into the unexplored regions of the aerial world, than a new oportu-

Chemical
method of
destroying
miasmata.

nity presented itself of inquiring into the nature and properties of those effluvia, that arose from the putrefaction of animal and vegetable substances, and which have in all ages been more or less looked upon as the origin of pestilential diseases.

Morveau.

Amongst those who made the first attempts to render the poisonous vapour of pestilence ineffectual by chemical decomposition, Morveau, a chemist of Dijon, is perhaps the best deserving of being recorded. He appears to have considered this matter as composed of volatile alkali, and an acrid animal oil in a gaseous, or aeriform state; and he informs us, that in May, 1773, the cathedral church of Dijon was found to be so very infectious and noisome, from the numerous inhumations, as to be no longer safe to frequent, whilst various substances had been employed to destroy it's cadaverous smell, such as large quantities of aromatics, vinegar, nitre, but without any effect, and under these circumstances this chemist was applied to.

It is a well known property of the muriatic acid, to take a gaseous form as soon as it is disengaged from it's combinations, but without losing it's acid character, or having it's energy diminished, and this was found to be of great use in purifying and destroying the infection of a mass of air, when loaded with putrid vapours. The method the commissaries of the Royal Academy at Paris had employed, in their report on the prisons of that city, was to add vitriolic acid to common salt, which disengages the muriatic acid in the form of white vapours, that immediately expand throughout the whole room or place where the process is made; and this has been found, to use the expression of these commissaries, to *neutralize the putrid miasmata*, and they recommend, as soon as the vapours are passed away, the doors and windows to be left open for two or three days, so that the

slight odour of the marine acid remaining may be dissipated, after which they found not the least danger of immediate habitation.

Morveau, with this previous knowledge of the good effects of this acid, applied it to the present instance of the cathedral. He supposed, that the acrid animal oil of the putrid effluvia, and which particularly affected the organ of smell, was supported in it's gaseous form by the volatile alkali, and that if a decomposition could be effected, the heavy fetid oil would fall down and be rendered inert. The vitriolic acid, formed by the combustion of sulphur, he knew would to a certain point accomplish this object; but as it rises very little, and after seizing upon the humid vapour, which it does with great avidity, loses it's heat and falls down again, it was incompetent to the task. He therefore placed a glass vessel prepared for the purpose in the middle of the church, put into it 6lb. of common salt somewhat moistened, and poured 2lb. of common vitriolic acid upon it, and immediately retired. He informs us, that he was scarcely got four paces, before a column of vapours of the muriatic acid had reached the ceiling of the church, and two hours afterwards, it was perceived through the key-hole of the most distant door. In about twelve hours all the doors were opened for the air to be cleansed of any remaining acid, but there was no longer any trace of putrid odour to be perceived.

The following year, another proof of the success of the same method was made in the prisons of Dijon. We are told, that 31 prisoners had died of the pestilential disease, called the jail fever, in less than three months, and means had been in vain attempted to destroy the cadaverous odour, by burning straw in the prison, but in twelve hours after the operation of the muriatic acid, the fetid odour was entirely destroyed, the danger of in-

habiting it no longer existed, and from that moment, the epidemic fever entirely ceased.

Others who have been employed in purifying infectious places, in consequence of epidemic diseases, recommend the same process, and advise it to be used as a precaution every year to preserve in particular the salubrity of prisons, and deprive them of infection.

Another form in which this acid has been employed, **Fourcroy.** is in it's dephlogisticated state. According to Fourcroy, whatever care is taken to keep anatomical theatres clean and inoffensive, either by sprinkling with vinegar, or by fumigations, it is found very incapable of preventing the dangerous effects arising from a large mass of matter, in a state of putrefaction; this enemy is the more terrible to anatomists, whose occupation is to reside within the reach of it's action, and the frequency of accidents from this source every year is well known. To oppose, therefore, an impenetrable barrier to this destructive agent, to prevent it's disastrous effects on those occupied in anatomical pursuits, and to destroy the germe of putrid and frequently fatal diseases, which these miasmata occasion, this chemist recommends the oxygenated muriatic acid, which he found to be the best shield against the poison of all animal putrefaction. He was led to it's use, from the effects it was found to have on odours of all kinds. Aromatics, the acid antiscorbutic, the poisonous narcotic, hepatic and sulphureous odours, were all destroyed by this vapour, and as it acts immediately on the odorous principle, alters it's nature, and changes rapidly the order of it's composition, it was supposed, that it was likewise capable of opposing these dangers arising from the miasma of putrifying bodies, and this chemist informs us, experience confirmed the supposition.

Another acid which was first employed by Dr. Carmichael Smyth, to destroy the contagion of the hospital fever, or jail distemper, is the nitrous acid. The cause of this fever he attributes to putridity. As a proof of this, he observes, that this disease is constantly produced where a number of people are shut up together in a close place, without the greatest attention to cleanliness and renewal of the air. Now it is well known, that all the excretions of the human body have already made a certain advance or progress towards putridity, and that when placed in certain circumstances favourable to putrefaction, they soon become highly putrid; amongst these, he thinks none is more highly animalized or more susceptible of becoming putrid than the perspiration or vapour issuing from the surface of the body and lungs; hence the animal perspiration may generate contagion, which contagion is found to show its baneful effects more quickly and forcibly in proportion to its quantity, and its being placed in circumstances the most favourable to putrefaction; consequently, in proportion to the size and closeness of the place, the temperature and moisture of the air, and the additional or accessory putrid matters with which it is combined; whilst on the contrary, the formation of this contagion is prevented by all those means that renew the air, and 'carry off' the perspiration, or prevent its tendency to putrefaction. In order to destroy the septic nature of this jail or hospital contagion, which he looks upon as one of the most subtle and powerful vapours of the putrid kind, from its immediate and destructive effects on the human body, several ways were employed. At first, when Dr. Carmichael was requested to undertake the cure of this disease, which was raging with great violence during the spring and summer of 1780, amongst the Spanish prisoners, confined

Dr. Carmichael
Smyth.

in the King's house at Winchester, he found great benefit from cleaning the parts of the prison affected by the contagious matter, washing the hammock posts with diluted muriatic acid, and throwing it by machines to the upper part of the posts, and even as high as the ceiling, at the same time the prisoners were well washed; but the most important part of the method he employed is the nitrous acid, which he informs us he used in two different forms, either in vapour from the yellow or smoking nitrous acid, or from nitre disengaged by the vitriolic acid; by which practice, both in hospitals, and in private practice for 16 or 17 years, he has obtained the most decisive evidence of its effects, in preventing the spreading or farther communication of contagion. Having found, that the most highly contagious fevers in hospitals do not effect the patients in general, lodged in the same ward, but only the nurses or those who assist them, or those who lie in beds contiguous to the sick, he has repeatedly prevented the farther spreading of the disease, by placing gallipots filled with the fuming nitrous acid, betwixt the beds of the sick, and of those who were not yet affected by the contagion; and in private practice, where the nitrous acid has been constantly used as a fumigation, he has not known one instance of a contagious fever having been communicated, even to a nurse or to an attendant. He is of opinion, that the well known efficacy of the sulphureous acid in destroying contagion, is a sufficient reason for its being continued as a fumigation for clothes, furniture, &c.; but as the nitrous acid is attended with no risk, or inconvenience to the respiration, and appears of sufficient efficacy to prevent the progress of the contagion, it is the proper antidote to be applied in all situations where persons are necessarily present; likewise in purifying empty hospitals or prison wards, or ships, as it is equally

efficacious with the sulphureous, it's vapour more volatile and penetrating, and it does not leave the disagreeable smell which sulphur does, when burnt. To obtain the nitrous or marine acid, in a state of vapour, as Dr. Smyth is of opinion, that all the mineral acids will destroy contagion, and are much more powerful than the most concentrated vinegar, he advises to decompose nitre or salt by heated vitriolic acid, half an ounce of which is put into a crucible, glass, china cup, or deep saucer; this is warmed over a lamp, or in heated sand, adding from time to time some nitre, or common salt; these vessels ought to be placed at 20 or 30 feet from each other, according to the height of the ceiling, or virulence of the contagion. In hospitals or prisons, the lamps or vessels containing heated sand may be placed on the floor; in ships, it will be better to hang them to the beams by waxed silk cords. As fumigating with nitrous acid is attended with no inconvenience, the process so simple, and the materials so cheap, it should be employed as a means of prevention, for some hours every day, in transports with troops on board, and in crowded hospitals; and if there be any appearance of contagion, the fumigation should be executed with more care and attention, and the vapour confined for several hours at a time. Fumigating vessels or lamps should also be placed contiguous to the hammocks, or beds, of persons affected with any contagious or putrid distemper, and by such precautions great mischief may probably be prevented.

A corroborating instance of the effect of the nitrous acid in stopping contagion is described by the same author. The experiment was conducted by Menzies, surgeon on board the Union hospital ship, which contained nearly two hundred sick, of whom one hundred and fifty were in different stages of a malignant fever, and highly contagious,

as appeared from it's rapid progress, and fatal effects. The utensils and materials for fumigation consisted of a quantity of fine sand, twenty-four great earthen pipkins, and as many small common tea-cups, with some long slips of glass as spatulas, the concentrated vitriolic acid, and a quantity of pure nitre in powder. The ports and scuttles being close shut up, the sand, which had been previously heated in iron pots, was scooped out into the pipkins by means of an iron ladle, and in this heated sand in each pipkin, a small tea-cup was immersed, containing about half an ounce of concentrated vitriolic acid, to which, after it had acquired a proper degree of heat, an equal quantity of levigated nitre was added gradually, and the mixture stirred with a glass spatula, until the vapour arose from it in considerable quantity. The pipkins were then carried through the wards by the nurses and convalecents, walking about with them in their hands, occasionally putting them under the cradles of the sick, and in every corner where any foul air was suspected to lodge. In this manner the fumigation was continued, until the whole space between decks was, fore and aft, filled with the vapour, which appeared like a thick haze. The body clothes and bed clothes of the sick were likewise exposed to the nitrous vapour as much as possible, the dirty linen removed, and immediately immersed in a tub of cold water, dried, and then fumigated before taken to the wash-house, a precaution very necessary in every infectious disorder; due attention was also paid to cleanliness and ventilation. The fumigation took up about an hour, and in an hour afterward the vapour having entirely subsided, the fresh air was freely admitted by throwing open again the ports and scuttles. The fumigation was repeated morning and evening, and it's pleasing and immediate effect in destroying the offensive and disagree-

able smell, arising from so many sick crowded together, was very perceptible; and so great was the benefit it produced, that not one of the attendants on the sick, or any of the ship's company, was attacked with the disorder after it was first begun.

The success of the same plan is likewise further attested by the subsequent letters of the same surgeon, and Bassan, who succeeded him; and from a similar experiment made on board some of the Russian men of war.

In making use of the nitrous vapour, it is necessary to distinguish that which is good from that which is hurtful. The vapour made use of by Dr. Smyth, by means of the vitriolic acid, poured on nitre in earthen or glass vessels, is white, highly dephlogisticated or oxygenated, and mixed with a large quantity of pure dephlogisticated air; and this fume is not only not suffocating, but has a pleasant smell.

The vapour, however, which arises in the usual process of distilling aqua fortis, as it is done in iron vessels, or which exhales during the solution of metals by the nitrous acid, is of a red colour, has been called phlogisticated nitrous acid vapour, and is highly suffocating and noxious; so that in preparing this vapour caution must be used, that no metallic or inflammable substance be admitted to the acid either by means of the vessels, or using iron spatulas or implements.

By this fumigation, therefore, it appears, that the process is both simple and easy; and although the vapour is extremely powerful and penetrating, the sick of every description are observed to bear it with little or no apparent inconvenience; and as it is found to purify the air from the disagreeable effluvia produced by so many people crowded together in a confined situation, of completely destroying the offensive smell, and contagious matter ari-

sing from putrid animal effluvia, or other animal matters; it will be peculiarly advantageous on board of sickly ships and hospitals, as well as prisons, where the clothes of the crew or patients may be fumigated at the same time as the apartments, without any risk of fire. At the same time it appears, that the advantages of the fumigation are not only experienced by those in health, whom it preserved from the baneful effects of the fever, but the sick and convalescents derived an almost equal benefit from it; the symptoms of the disease were meliorated, and lost much of their malignant appearance, and the advantage of an air pure and free from stench to convalescents must be very great.

Dr. Carmichael Smyth has, in a *description of the gaol distemper*, given an examination of the different means hitherto employed to destroy the gaol contagion. These he arranges under two classes, viz. the physical and the chemical. He says, that contagions, whether specific or putrid, are either checked or completely destroyed by the extremes of heat and cold; and by a free exposure to air and water are so diluted or dissolved as to lose their noxious quality. These four are therefore physical agents. A degree of heat nearly equal to that of the oven is found necessary for the complete destruction of contagion, and may be used in purifying clothes, furniture, &c. Heat is likewise, when judiciously managed, a check to its progress; for as closeness and dampness are favourable to the production and spreading of contagion, drying and rarifying the air, by counteracting these, must be, at least so far, proper antidotes. Independent, however, of heat, an open fire, especially where the fuel is burnt in a narrow flue, is of great benefit, as being one of the best ventilators. The degree of cold necessary to destroy contagion is probably, like the degree of heat, inconsistent with

life, and therefore, although we hear of contagion having been checked or suppressed by cold, there are few instances, if any, of it's being completely destroyed by it.

That noxious vapours are hurtful only when concentrated, and are harmless when diffused, are facts universally admitted; and hence clothes, bedding, or other things to which contagion adheres, are purified by a certain length of exposure to the open air, or to a current of water; but as the time requisite for this mode of purification is uncertain, and as contagious clothes and goods, &c. cannot always be exposed in a proper manner, the more expeditious means which chemistry affords must be had recourse to: and as Dr. Lind has very properly remarked, that no ventilation or admission of air or water into prisons or hospitals can remove or destroy contagion when once present, although both may be usefully employed in blunting it's force, chemical agents are absolutely necessary. These Dr. Smyth examines. The chemical agents hitherto employed for destroying contagion, are,

1. *Burning sulphur with charcoal, or with arsenic.* The vapour from the burning of sulphur is remarkably volatile and powerful, and it's effect in destroying contagion has been long established, but as even in small quantities it affects respiration, producing suffocation and death, it can only be employed for fumigating clothes, furniture, or empty apartments. The occasional addition of arsenic seems to have been made by Dr. Lind, with a view of increasing the deleterious quality of the vapour; but it appears unnecessary, as the sulphureous acid is sufficiently strong, and perhaps the vapour of arsenic is too heavy to rise with the acid of sulphur.

2. *Burning or deflagrating nitre.* As there is no nitrous acid produced, it can be of no use except so far as the oxygen may be of service.

3. *Burning gunpowder* and port-fire (one half sulphur, one quarter nitre, and as much charcoal) can be of no use.

4. *Tar, tobacco, and wood* when burnt (although Dr. Lind appears to have had a high opinion of the second, and looked upon the third to be one of the most powerful means of destroying contagion) cannot be of any service.

5. *Vinegar*. This, although much boasted of, Dr. Smyth never saw of any service; but the steam when united with camphor affords a reviving smell to patients. Washing the furniture, floors, and walls with vinegar, is little better than common water, and the same may be said of white washing, and oil painting.

The most powerful agents, perhaps, after fire, are the mineral acids, particularly when in a state of vapour, with the different gases or permanently elastic fluids produced by them; and as they are known to have a great influence over putrefaction, and those other spontaneous changes which vegetable and animal matter, deprived of life, undergoes, they certainly must be very efficacious in destroying the gaseous contagion, which, according to Dr. Smyth, is a vapour produced by putrefaction.

As the volatile sulphureous acid vapour, though effectual in destroying contagion, cannot be employed except in situations from which people can be removed, Dr. Smyth made some experiments with the vapours of the other acids upon mice, birds, and upon himself; and found the different acid vapours, in respect to the safety with which they can be breathed, may be arranged in the following order:

1. *The vapour of nitrous acid, arising from nitre decomposed by vitriolic acid*. This is perfectly harmless in any quantity in which it may be required, there not being the least risk in breathing it. For this purpose, the fumigating lamps sold at Moyser's, in Greek street, Soho, may

be employed, a great number of which are sold to the navy, but they would answer much better if the faucer was deeper; and if, instead of a place for a lamp, there was a box proper for containing hot sand, in which the faucer might be placed. This nitrous vapour appears to be the *desideratum* sought after by Dr. Lind.

2. *The vapour of nitrous acid in it's fuming state, or when the nitrous acid is mixed with nitrous gas.* This, though more pungent than the first, Dr. Smyth believes may be employed with the greatest safety, having never known any inconvenience from using it. But as it was more difficult to procure, and is attended with greater trouble and expence, he has always used the first.

3. *The vapour of marine acid, arising from common salt, decomposed by vitriolic acid.* This, though more stimulating and more apt to excite coughing than the nitrous, may be safely used, at least in a moderate quantity, where people are present; and where nitre cannot be had, Dr. Smyth would not hesitate to employ it.

4. *The vapour of nitrous and marine acids from nitre and common salt by vitriolic acid.* This, on being heated, was more pungent than the pure marine acid, and therefore unless it be found more efficacious in destroying contagion, should not be used where people are present.

5. *The vapour of sulphur burnt with one-eighth part of nitre.* This can only be used with safety when there are no people present; hence must be solely confined to fumigating empty apartments, clothes, furniture, &c.

6. *The vapour of sulphur burnt with charcoal.* This should never be employed, as the carbonic acid may do harm, and never can have any effect on contagion.

7. *The vapour of oxygenated marine acid, by distilling marine acid from manganese.* Dr. Smyth says, he only knows it is extremely deleterious.

Dr. Smyth found the marine acid, when properly diluted, proved completely effectual in destroying the contagion at Winchester prison, by washing the hammock posts, walls, and floors of the prison ward, as well as the other furniture with it; and in this respect it is certainly more powerful than the most concentrated vinegar.

French chemists, their method by marine acid vapour.

Since Dr. Smyth's experiments upon the mineral acids, the French chemists and physicians have published a paper on the means of destroying contagion. It is entitled, "*Instruction sur les moyens d'entretenir la salubrité, & de purifier l'Air des Salles dans les Hôpitaux militaires de la République, fait au Conseil de Santé, le 5 Ventose, l'an 24 de la République.*" From this *mémoire* it appears, the French physicians, instructed by Guiton of Dijon, have lately made trial of the vapour of marine acid in their hospitals, and have found it equally as effectual in destroying contagion as the sulphureous, and, as being more volatile, perhaps even preferable for the purpose of purifying hospital wards. They also remark, that in a smaller proportion, it may be safely used in hospital wards, even where people are present, and the experiments of Dr. Smyth prove the same. The method the French physicians employed to obtain the marine acid vapour, is either by employing the fuming marine acid, or the acid detached from it's alkaline basis by vitriolic acid, using a considerable degree of heat for this purpose. The process for a room containing from forty to fifty beds is, after having taken out the patients and closed the doors and windows, to heat nine ounces of muriat of soda (common salt) slightly moistened with half an ounce of common water, and pour upon it four ounces of sulphuric acid or common oil of vitriol, having previously placed the apparatus in the middle of the room. In an instant the sulphuric acid acts upon the common salt, and the ma-

rine acid expands itself, the person taking care to leave the room immediately, and to lock the door. In twelve hours after, the doors and windows are to be opened to let the currents of air evacuate the acid.

This is likewise employed in the rooms filled with patients, when there is reason to suspect them of containing animal miasmata; but in these cases one third part only of the above mixture is employed, or even less, carrying it into every part of the room where any infection may be supposed to lurk. After the chambers are sufficiently full of the vapour, the apparatus is put into the necessaries or privies, to decompose or neutralize any bad or putrid exhalations they may contain.

Van Mons, in a report made to the Society of Medicine, at Brussels, with respect to the means necessary for purifying the air in the apartments of the sick, opposes the method of fumigation, as it diminishes the respirable, and adds to the unrespirable air; in general, he found the air in such apartments to consist of abundance of carbonic acid, hydrogen, oxygen, and azotic gases; sometimes a little ammoniacal gas, and a peculiar emanation, called *contagious miasma*, which appears to him to be a peculiar combination of hydrogenous carbonic acid gas, holding in solution animal fluids very little known. The hydrogen gas contains almost always in solution pure carbon, phosphorus, &c., from which the disagreeable odour arises. The carbonic acid would form a much more considerable part, according to this chemist, were not this gas continually neutralized by the ammonia evolved in all diseases where animal substances containing azot are decomposed. Hence the contradiction of those who suppose air to contain carbonic and ammoniacal gases at the same time, and the absurdity of exposing vessels filled with quicklime in the apartments of the sick, which takes away the carbonic acid gas, and leaves the

ammoniacal. Among the best means of purifying infected air, this chemist classes vaporized water, which incommodes the patient less, and deprives air of it's putrid effluvia better than the muriatic or acetous acid, or than spirits, being a better solvent than these. The sulphureous gas he thinks might decompose the miasmata by giving them a portion of it's oxygen, but it leaves behind it an oxyd of sulphur, the smell of which is very offensive; hence oxygenated muriatic acid is preferable. (*Annal. de Ch.* vol. 29, p. 99.)

With respect to the offensive smell of different places, such as privies, night-chairs, &c., an object of such consequence with respect to health and comfort, the most cheap and effectual means of destroying it is the following: If a certain quantity of milk of lime (water in which lime has been recently slacked and poured off previous to it's setting) be mixed with a ley of ashes, or even soapy water that has been used for washing, and thrown into the sink of a privy, or other convenience for the sick room, it will immediately destroy the offensive odour. It is obvious that a more simple method is, to mix a few pounds of quick lime with a small quantity of wood ashes, and a bucket of water.

The spirit of energy which the pneumatic method of considering the causes of pestilence has introduced, has already created a formidable opposition against fumigations, and the destruction of contagion by acid vapours.

Dr. Trotter. Dr. Trotter informs us that several years ago, or in 1793, he had no faith in the fumigating process, and that the acid vapours, particularly the nitrous gas, must be prejudicial to those who are exposed to them.

The offensive effluvia, so disagreeable to the smell, which the acid is to destroy, are, according to Dr. Trotter, sulphurated hydrogenous gas (hepatic gas), the aerial product of fœcal matter, and such as ascends from privies; phos-

phorus and carbon may also be mixed with it ; the nitrous gas certainly decomposes it, and sulphur is precipitated and the smell vanishes. In the same way the nitrous acid alters the effluvia of the confluent small pox, when they approach beyond maturity ; and also the offensive matter of large sloughing ulcers, which do not materially differ from the vapours arising from the faecal mafs. The nitrous gas, according to the same author, decomposes the carbonic sulphurated hydrogenous gas of gunpowder fumigation, and takes away it's smell ; the oxygen of the nitrous gas combines with the hydrogen, and forms water, and the small portion of azot, with the sulphur and the carbon suspended in the hydrogenous gas, is precipitated, and the smell disappears ; but Dr. Trotter thinks, that the nitrous gas, when employed against contagious effluvia, not only adds nothing to the improvement of the qualities of the air which support life, but that it is introducing a substance that takes away part of the remaining oxygen of the atmosphere, and the different perfumes used as fumigations render the air more noxious, by giving out hydrogenous gas. He thinks, that although the aromatic vinegar of the Edinburgh Dispensary, vulgarly called the vinegar of the four thieves, is of all perfumes the most grateful, yet it's effects on the atmosphere cannot be great, and vinegar, which he suspects gives out oxygen by evaporation, had better be used alone. He supposes, that by the fumigating process of Dr. Smyth, the very substance is introduced which ought to be avoided, and which is the vehicle, if not the noxious cause itself (the septon of Dr. Mitchill), and the experiments of Reilly, Browne, and Moffat, on board different vessels, he thinks have confuted the practice of it as a fumigation. He looks upon the noxious gases evolved from excretions of the sick to be the vehicles of the infection ; and he considers heat as one of the most powerful correc-

tors of contagion ; it rarifies foul air, or that spoiled by respiration in crowded apartments; applied to substances imbibed with animal miasma, it will either dissipate it or convert it into an inert mass, so as to be harmless ; it will dry up moisture, and above all, it is useful as a general stimulus to the body, by keeping it warm, and thus fortifying it against cold, which so evidently tends to dispose it to receive infection : hence the whole preservative means are comprised in the removal of the sick, cleanliness, fires, and ventilation. It is evident, that the opinion of Dr. Trotter is the same as that of Dr. Mitchill respecting the use of nitrous acid gas, who looks upon it to be the most preposterous and ill-contrived method that can enter the mind of man. Such are the principal methods that have been employed to destroy the putrid exhalations arising from the decomposition of animal and vegetable substances, and which are called *miasmata*.

Conclusion. *Conclusion.* There now remains to recapitulate the principal facts, and to conclude the subject of putrefaction.

Upon recalling to mind the principal phenomena attending spontaneous decomposition, it has been seen, that animal matters, which are composed of hydrogen, carbon, oxygen, and azot, and which are often still more complicated by the union of sulphur, phosphorus, &c., on being deprived of life, and of that constant action and renewal of their component parts, that appear to constitute it, soon begin to change by the more simple attractions taking place between each of their principles, which tend to unite by pairs. This gives rise to binary compositions, such as carbonic acid, nitric acid, ammonia, and carbonated hydrogenous gas, which, on being disengaged by degrees into the atmosphere, diminish in proportion the mass of animal matters. Hence it is in consequence of this natural decomposition, that these matters are observed to become soft, to change their co-

lour, their odour, lose their texture, form and distribute vapours and gases into the surrounding element, which serve other bodies, particularly vegetables, with the necessary materials for their formation; or, under certain circumstances, are converted into the most deadly poisons. All the phenomena attending the putrefaction of animal substances are derived from the above sources. From the union of the hydrogen with the azot, arises the formation of ammonia, which has been looked upon as the principal product of putrefaction. The combination of carbon with oxygen, explains the formation and disengagement of carbonic acid, which, on its first discovery, was supposed to explain all the mysteries of putrefaction. The nitric acid, to the formation of which animal matters are known to contribute so much in the manufactures of nitre, arises from the union of the azot with the oxygen, whilst a certain quantity of hydrogen gas being disengaged, and carrying with it carbon, sulphur, and even phosphorus, is said to create that variety of putrid odours, and that phosphorescent light observed in all animal substances during the putrefactive process.

These volatile principles being united in pairs, and expanded through the atmosphere, there only remains a little carbon united or mixed with some saline matter, as the phosphates of soda and lime. Sometimes it happens, that even the acid of these salts is decomposed, and its radical seized by the hydrogen, so that nothing more is found than the alkali or the earth which served for a basis united to carbonic acid. These residua form a species of earth, called *animal earth*, that often retains a little sulphurous and carbonated hydrogenous gas, a little oily matter, and an extract in which the vegetable creation finds abundance of materials necessary to their increase, which is the reason why this animal residuum is found to be so beneficial as a manure.

A certain quantity of water, it has been observed, is

necessary for the putrid decomposition; according to Fourcroy, and some of the French chemists, it furnishes the quantity of oxygen for the formation of the carbonic and nitric acids, and it contributes singularly to the putrefactive process, by its affinities. They look upon the hydrogen likewise, arising from this decomposition of water, to contribute its part in forming ammonia, since it is a well known fact, that when animal matters are rendered more dilute by a large proportion of water, they afford, during their decomposition, ammonia in great abundance.

Putrefaction consisting in a succession of particular attractions, and forming new combinations; it is evident, that all exterior circumstances, as temperature, a dry or moist atmosphere, the situation of the matters, the medium in which it is carried on, &c. will cause a variety in its effects; hence bodies that are suspended in the air, inhumed in the earth, or plunged in water, will undergo various modifications in their decomposition, which will likewise be diversified by their quantity, their mass, their connexions with neighbouring bodies, and other agents, the number and activity of which are at present unknown.

Hence bodies exposed to the air are soon decomposed, or if inhumed in an isolated state, surrounded by a large quantity of earth, they are soon destroyed, and their æri-form or liquid products are absorbed either by the atmosphere, or the soil around them, whilst on the contrary, when heaped together in masses, in a deep earth that has been saturated to excess with the effluvia and volatile products of putrefaction, it can no longer influence their decomposition by its disposition to receive or favour the new combinations that take place; hence they remain a long time undestroyed; the animal matter is wholly converted into ammonia, and a concrete oil, forming a soap, as discovered by Fourcroy in the churchyard of the Innocents.

The phenomena of decomposition of bodies plunged in water are still different, for in proportion as new products are formed, the water dissolves them and distributes them into the atmosphere. A continued humidity, with a prevailing temperature of a few degrees above zero, favours the putrefaction, and the solution of these matters into a gaseous form; on the contrary, a dry and hot air, by evaporating the water, dries animal bodies and converts them into mummies, in the same manner nearly as the sands of Egypt.

Although the numberless varieties, which the phenomena attending putrefaction present to the observer, are at present undescribed, and even unknown, yet the grand purpose to which they all tend is evident; life, contrary to the chemical affinities which the component parts of bodies have towards each other, had forced them into organized combinations; but being deprived of this principle, they resume again the affinities they were deprived of, and by means of putrefaction become united into less complex forms. This process, without which both animal and vegetable bodies would remain useless and inert, reduces them, therefore, to the materials of which they were composed, in order to form a new creation, and whilst it attests the simplicity and grandeur of the operation, it expresses the fecundity and power which are so well comprehended in the philosophical expression of Beccher, the *circulus æterni motus*, by which he meant to pourtray the never ceasing activity of nature.

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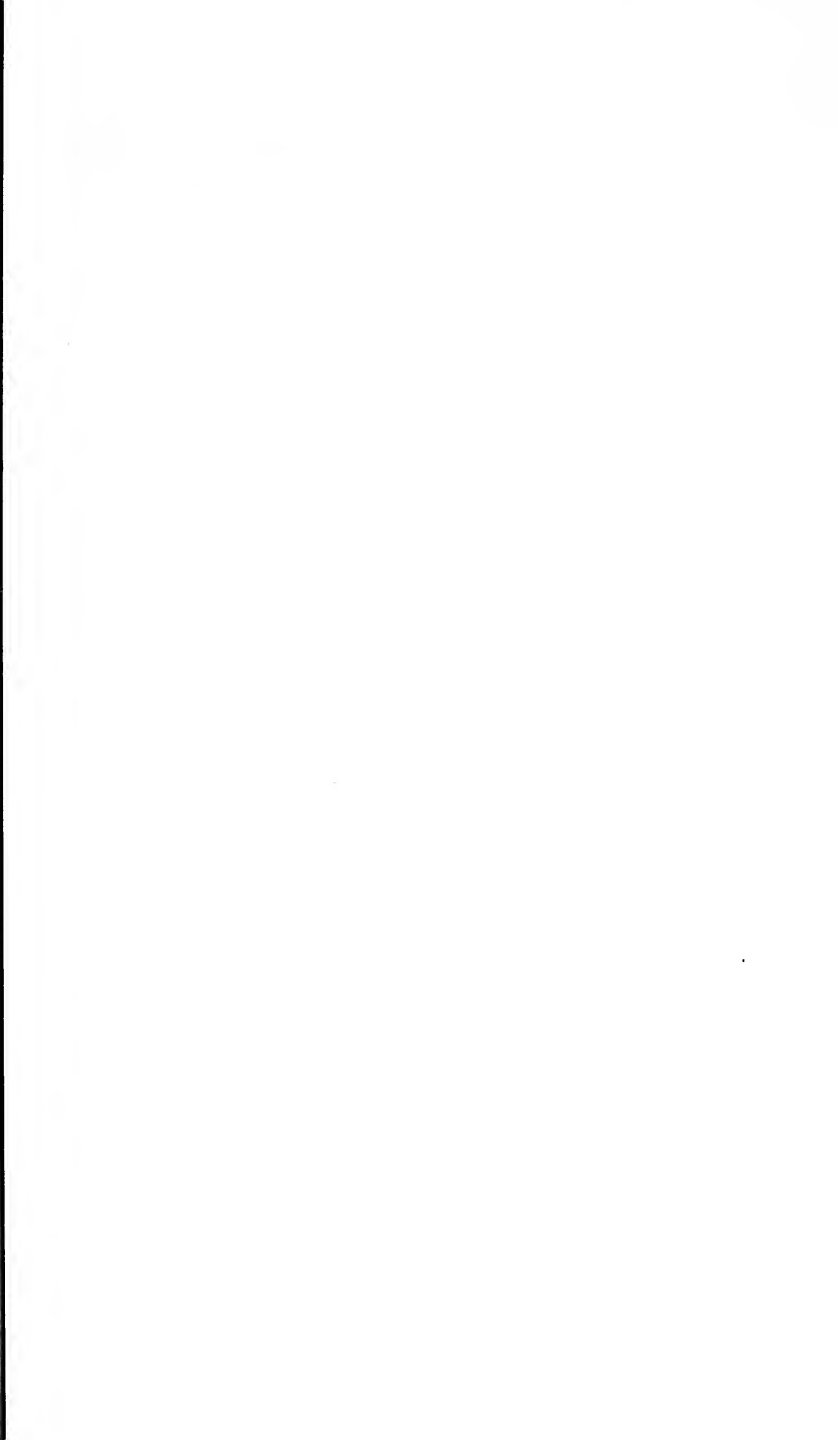
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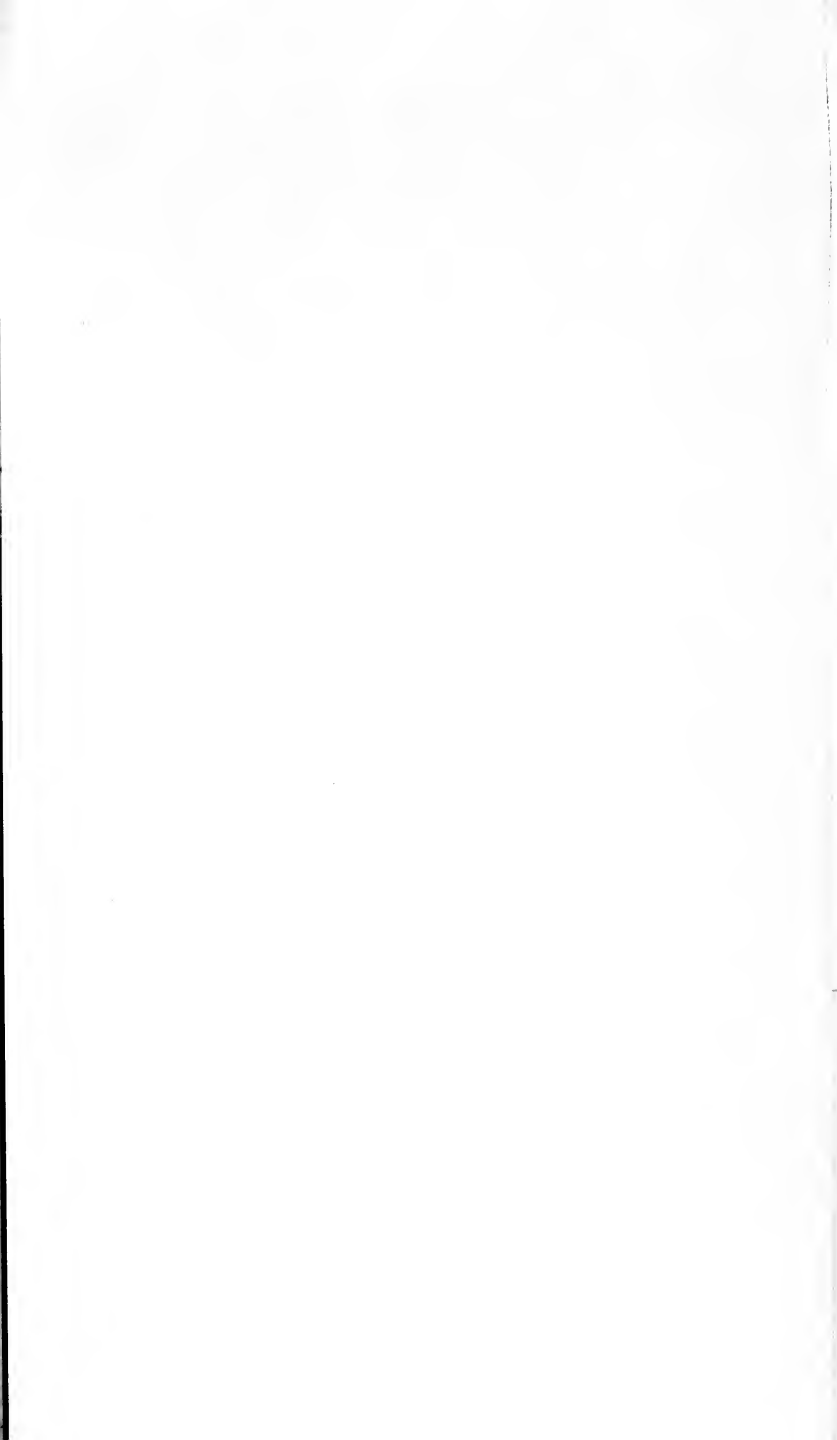
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